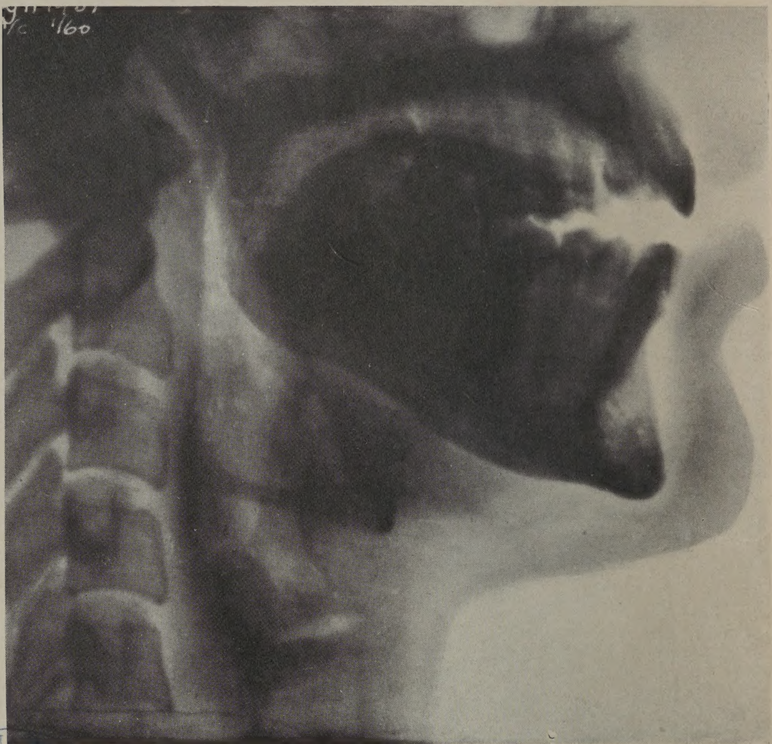

The X-ray picture of the vocal organs.

[*Frontispiece*

THE MECHANISM OF THE HUMAN VOICE

By

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FOREWORD

Voice and speech are of such supreme importance to mankind that one might well envisage an enormous literature dealing with the subject in all its complex details. Such a literature does exist, but the numerous writings are scattered throughout the pages of divers journals; indeed, the science and art of vocalisation is so many-sided that few persons possess the knowledge necessary for a complete understanding of its many problems. A number of books have been written on the vocal mechanism, most of them by teachers of speech and singing and a few by physiologists and laryngologists, but so far as I am aware there is no work which describes, in accurate scientific language, without bias or prejudice, the present state of our knowledge of the human voice, with due reference to all the ascertained facts, whether anatomical, physiological, physical or psychological. To the difficult task of collecting and assessing this great mass of information, Dr. Robert Curry has addressed himself during the past eight years, and he has now succeeded in producing a book which will be immediately recognised as an authoritative work of reference. Dr. Curry was well qualified to undertake this work. After graduating with honours in English he devoted himself to Education and then, successively, to Physics, to Phonetics and to Psychology, and finally he studied Anatomy, Physiology and even Laryngology.

To those familiar with the subject, his researches on the physics and physiology of voice and his methods of recording voice by radiography and by the cathode ray oscillograph are well known. This work was carried out at Ohio State University with the aid of a Commonwealth Fund Fellowship, and has been continued in University College, London, under the terms of a Beit Fellowship.

While Dr. Curry was in Edinburgh it was my good fortune to collaborate with him in some investigations of laryngeal action by means of the stroboscope and in the study of various methods of breathing and the production of voice. I then formed a high opinion of his wide knowledge, his technical skill and his accuracy of observation, and it is with great pleasure and much confidence that I commend to the reader this lucid and comprehensive account of the mechanism of the human voice. It should appeal to a large audience, composed of medical men, scientists, teachers of speech and song, and many others, for surely the subject deserves the attention of everyone at a time when the spoken word is so powerful a factor in the progress of the world.

DOUGLAS GUTHRIE.

EDINBURGH.

PREFACE

The motive in adding this book to the already extensive literature on the subject of the human voice has been the hope that it will serve to clarify and correlate some of the many diversified lines of study. There is, I feel, an increasing demand for a comprehensive study of the mechanism of the human voice that shall be as exhaustive as possible in view of the limitations of an individual understanding. Therefore, this book is designed not so much to supplant the available sources of information, whether in anatomy, physiology, phonetics, psychology, singing, etc., but to amplify and correlate these in the very aspects which are less adequately treated. It would have been impossible in a book of these dimensions to treat in detail all the minor aspects of the study, and so it has been the intention to give a guide to the study in general, with indications of sources in which the interested student may find more extensive discussion. Within the scope of the restricted bibliography reference has been made to the available sources. I trust I will be forgiven if sometimes I fail to acknowledge completely all my indebtedness to those with whom it has been my privilege to study.

I am conscious of especial indebtedness to some who have stimulated me in this work by their kind training, encouragement and direction. I should particularly like to acknowledge the kindness of Professor G. O. Russell, of Ohio State University, Dr. Douglas Guthrie, of Edinburgh, Mr. H. Orton, of King's College, Durham University, and Professor J. Drever, of the University of Edinburgh.

I am grateful to the following for permission to reproduce certain illustrations in this book. To the *Oxford University Press*, for Fig. 3 ; the *Revue de Laryngologie*, for Figs. 13 and

15; the *Archives Néerlandaises de Phonétique*, for Fig. 19; the *International Phonetic Association*, for Fig. 16; the *University of Durham Philosophical Society*, for Figs. 1 and 2; Dean C. E. Seashore, of the University of Iowa, for Fig. 17, and Professor A. Gemelli, Rettore dell' Universita cattolica del Sacro Cuore, Milan, for Fig. 18. I am very grateful to my friend Dr. Tarneaud, of Paris, for the many facts referred to throughout the book. Professor Lovatt-Evans, of the Department of Physiology, University College, London, very kindly read the manuscript, and I am indebted to him also for giving me accommodation during the composition of the material. Finally, I have pleasure in acknowledging the assistance I have received over a number of years from the Research Fund of King's College, Newcastle-on-Tyne, which has made possible the appearance of this book.

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CONTENTS

MECHANISM OF THE HUMAN VOICE

CHAPTER I

INTRODUCTION: THE NATURE OF VOICE

§ 1·1. Normal human voice may be defined as the audible product of vibratory action of the vocal organs. The types of voice may be classified into two groups according as the action of the vocal organs is voluntary or involuntary. Involuntary forms of voice are firstly, those audible accompaniments of muscular effort such as the grunt, groan and sigh, or secondly, the audible effects of such action of the vocal organs not directly intended to produce voice but utilizing the same mechanism, usually some form of laugh, cough, hiccup or sneeze. These involuntary forms of voice are highly variable and peculiar to the individual and may occur in voluntary speech in a quasi-automatic fashion under the stimuli related to the original situation.

§ 1·2. The voluntary part of voice is concerned with the three accepted forms of whisper, speech and singing. Whisper may be considered as a specialized form of speech utilized under special circumstances for an effect of concealment and consisting of the recognizable content of normal speech produced at minimum audible intensity and with minimum larynx action. Speech is the audible form of voice directed in established ways to communicate with other individuals. Singing is an artistic form of voice modified by melody and rhythm to produce a pleasing harmony of music and voice, generally with instrumental accompaniment. In whisper the dominant fundamental pitch of the larynx vibration is absent and the sound is most variable, least easily audible and nearest in quality to noise. In speech the dominant fundamental pitch of the larynx vibration is present in about 60 per cent. of the duration and the sound is of an audibility

and clarity, depending upon the attention of the speaker, the accuracy of his vocal movements, the normality of his hearing and the linguistic training of his education. In singing the larynx vibrates during at least 90 per cent. of the duration and the sound is audible, clear and attractive, depending upon the capabilities of the singer.

§ 1·3. Certain actions of the vocal organs do not result in audible products because the respiratory mechanism does not provide the necessary flow of air. The involuntary types of these actions are the dropping of the lower jaw in astonishment and the contraction of facial and buccal muscles as in staring, clonic spasms and aridity of the mouth and throat. The more or less voluntary form is exemplified especially in the so-called silent speech, in which the vocal organs carry out more or less completely the normal speech actions but do not produce audible sound. Gesture may also be considered a form of this action and it is claimed to be the origin of overt, audible speech. Paget, **160**; Bloomfield, **73**.

§ 1·4. In dynamical terms voice consists of two components: Firstly, a more or less steady stream of expired air; and secondly, and more important, a progressive wave of vibratory motion of air molecules. Normal voice consists of expiratory function, but there exist certain languages (African dialects, etc.) in which the inspiratory phonation may occur, especially for stop consonants. This abnormal inspiratory voice may come also as a disorder or pathology of normal voice. Nadoleczny, **319–20**. The stream of air may constitute part of voice in the form of audible vibratory motion in various parts of the speech system excited by obstacles in the free air pathway. Examples of these speech-sounds are aspirate and fricative voiceless consonants, which in English form about one-quarter of the content of spoken language. In whisper the whole of the sound is produced by the air stream without laryngeal vibration. But the direct pressure exerted by the air stream would not affect an ear placed further than about 2 in. from the mouth of the speaker, while the progressive vibratory sound-wave may be audible at great distances.

In the absence of larynx vibrations at the vocal cords, the sound-wave is produced as the summation of vibratory motion in various regions of the speech system, consisting of natural cavity resonances, eddy current vibrations near constrictions in the passage, or edge-tones produced by obstacles in the air pathway. It is possible also that small globules of the mucous coating of the pharynx may vibrate as obstacles. The vibrations in or near the larynx may be the normal vibration of the vocal cords, or the abnormal substitution mechanism formed of vibrations of the ventricular bands, of the mouth of the œsophagus, or the approximated surfaces of the tongue-root and pharynx-wall.

The Development of Voice

§ 2·1. The priority of the vocal over the written language is not always recognized. Every written language has or had a vocal original, yet many languages exist only in the vocal form. Voice is the initial source of language and the basis of civilization, and many theories of origin have been propounded. The early Greeks considered voice to be a divine gift. Later theories pointed out the occurrence of involuntary sounds accompanying strong action of the chest and arm muscles. The so-called ' gesture ' theory points to the possible origin in movements of the speech organs imitating mass bodily reactions to various types of situations or stimuli. Thus in climbing or expressing the concept of elevation (hence, height) the tongue may rise up to the palate, or the mouth may close, and the accompanying vocal sound would be [l] or [p]. It is possible only to theorize because the available records of early languages show an already complex structure. The acquirement of speech in childhood is conditioned by very different factors of environment of established language and pressure forcing the acquirement of a given vocal pattern. Voice has a purposive function and so speech consists mainly of actor-action relationships or commands. Accordingly, voice may have originated in the first conscious attempt to control the actions of others.

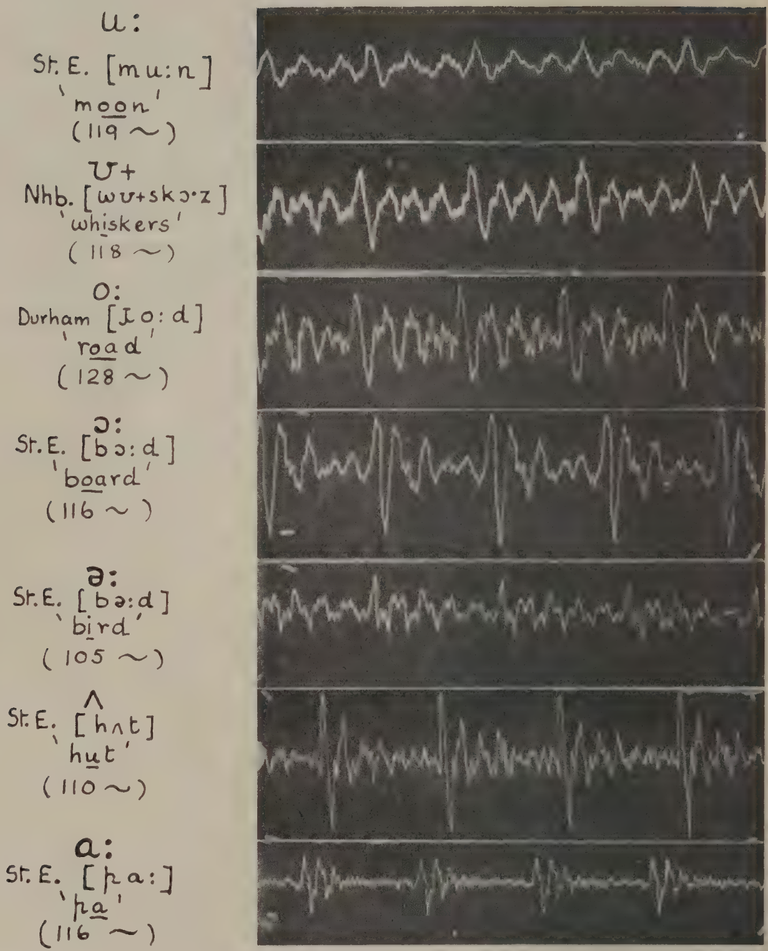

FIG. 1. Cathode ray oscillographic records for Standard English (St. E.) and Northumbrian (Nhb.) vowel sounds. (*Courtesy of University of Durham Philosophical Society.*)

Speech is largely used as signals in given situations. The statement of meaning is the weakest factor in language and in practice the meaning of a linguistic form is defined in terms of some descriptive science referring to attributes of the object meant. The historical development of the variant forms of speech is very obscure. A sound change in speech is an historical event, with a beginning and an end, limited to a definite era and a definite speech community. The motivation of the sound change is frequently obscure. Racial differences cannot account for speech differences on the basis of comparative anatomy ; the anatomical differences between members of the same speech community are as wide as those between members of different communities.

Definitions

§ 3·1. Definitions of the terminology used in physical descriptions of voice are given in Chapter III, but it is important to define here some of the aspects of singing. A sung tone is that product of voice as modified for the requirements of singing. In most sung tones we distinguish an artistic feature consisting of a periodic modulation of pitch and/or intensity occurring about seven times per second and called the Vibrato. Tonal power is defined as the maximum mean power of a sung tone as plotted in graphical form against time. The initiation of a sung tone is termed the Attack and the termination is the Release. Tones are over-held or under-held when they are sung for longer or shorter periods of time respectively than indicated by the musical score. The term ‘ Register ’ is used loosely in singing to describe firstly, certain ranges of sung tones, or secondly, different audible qualities of singer's voice. The compass of the voice is the range of pitch change over which the singer can produce normal voice without straining or change into the falsetto. Transitions are stages in the act of singing over the compass at which the singer is compelled to make a physiological change in the larynx vibration mode in order to proceed higher in the compass. The falsetto voice is an abnormal

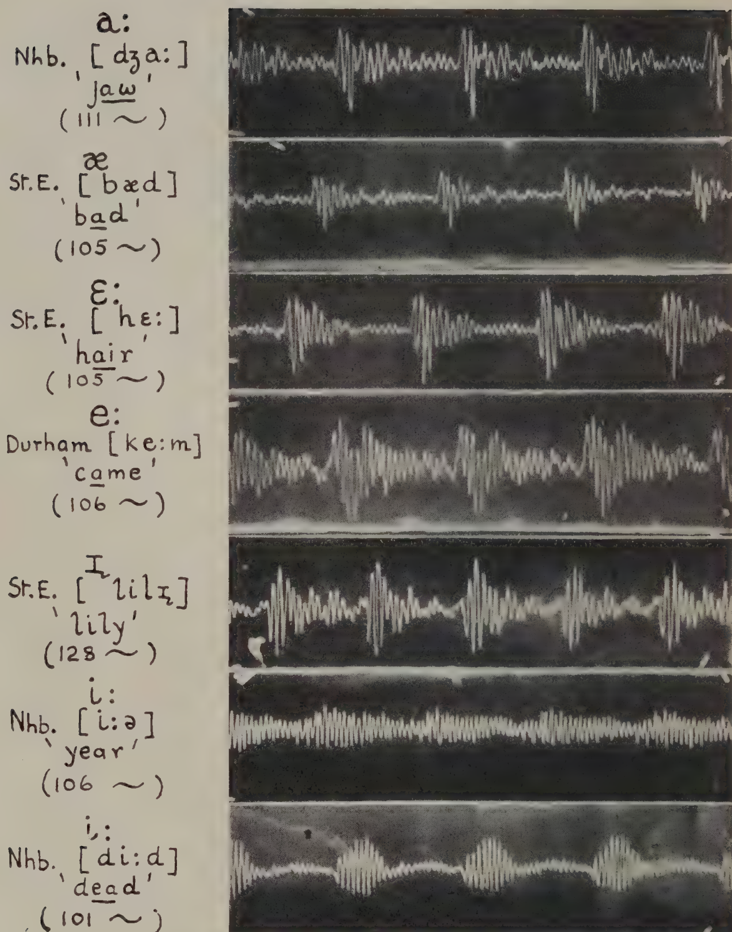

FIG. 2. Cathode ray oscillographic records for Standard English (St. E.) and Northumbrian (Nhb.) vowel sounds. (*Courtesy of University of Durham Philosophical Society.*)

voice in that it is produced above the normal compass range and requires an altered mode of larynx vibration. In the male voice it involves a quality change towards the female voice.

The Cortical Control of Voice

§ 4·1. The cortical control of voice may be considered under the three aspects of respiration, phonation and articulation, though voice requires, naturally, a co-ordination of all three activities. Normal respiration is mainly an automatic act of a reflex type though subject to a certain degree of voluntary control, since it can be modified though not suppressed by voluntary effort. The act of respiration involves action of the muscles of larynx, thorax, diaphragm and abdomen and hence is controlled by a co-ordination of the nerves from various parts of the cerebro-spinal axis. Apparently, normal respiration is controlled from a centre in the medulla which is bilaterally represented. Thomson and Negus, **250**, p. 592. Inhibitory and acceleratory control are functions of the cortical centres. Smith, **353**, p. 64. The participation of the serratus magnus muscle in respiratory action may be determined by its innervation from the long thoracic nerve from the 5th, 6th and 7th cervical nerves.

§ 4·2. The cortical representations of the functions of voice form a subject of some dispute among the authorities. A sensory termination of the vagus nerve has been found to lie in the orbital surface of the frontal lobe (regions 6a and 6b of Brodmann) near the precentral gyrus. Bailey and Bremer, **254**, p. 412. The inferior laryngeal nerve, which controls the majority of the larynx intrinsic muscles, can be traced in the trunk of the vagus to bilateral centres in the medulla in the floor of the 4th ventricle. At this level, destruction affecting one centre would affect only one vocal cord, that one on the same side. Thomson and Negus, **250**, p. 593. Above this level the decussation of cortico-bulbar fibres causes the reversal of hemispheral control so that the left hemisphere controls the right side of the body, the dominant side in the

average individual. Apparently, in the average person, who is right-handed, the left hemisphere is dominant over the right hemisphere in the sense that the speech association areas in the right hemisphere are inactive while those in the left hemisphere are active and in control. This factor is associated with the claim of distinction of a special area in the left hemisphere, known as Broca's area. The location of this area is generally given as the posterior extremity of the inferior frontal gyrus (Brodmann's areas 44, 45 and lower part of 4 and 6b). It is considered that the cortical centres for speech are : the precentral gyrus, the posterior, triangular and orbital parts of the inferior, frontal gyrus, and the superior, middle and inferior temporal gyri as far back as the parietal lobe and excluding the temporal lobe and the nuclear region of Heschl's transversal anterior circumvolution. Strasburger, **359**, p. 38.

§ 4·3. The dominance of the left hemisphere in the right-handed person determines handedness and eyedness and apparently to a great degree language functions. However, it appears from studies of aphasia that the association areas may be represented in the right hemisphere as it were in a state of receptivity for language control, the degree varying with the extent of the dominance of the left hand in writing. Weisenburg and McBride, **252**. Fairly well-spread lesions, centring in or near Broca's area, are especially associated with disorders of verbal symbolism and motor language dysfunctions such as hesitation, mispronunciation, poverty of vocabulary, etc. Apparently the division of control between the cerebellum and the cerebral hemispheres is manifested in speech by the varying impairment of less or more highly integrated linguistic functions in cases of cerebral lesions. Jasper, **195**. The cortex is apparently occupied in the control or repression of higher over lower level responses, and thus the less highly integrated movements, such as the reflex linguistic responses to stimuli or emotions, are preserved, when the more highly integrated actions leading to language are impaired or destroyed.

CHAPTER II

THE ANATOMY OF THE VOCAL ORGANS

§ 5·1. It is customary to divide up the consideration of the mechanism of voice under three interrelated studies, viz., respiration, phonation and articulation. For voice the normal respiratory cycle is modified and disturbed to produce a prolonged, expiratory stream of air which constitutes the initial force of voice itself. The act of phonation consists of the vibratory movement in the larynx producing the acoustic effect heard as voice. Articulation is the part played by the supralaryngeal organs in modifying the sound wave produced at the larynx. These three actions are secondary functions that have been developed upon the primary functions of breathing, swallowing and eating.

§ 5·2. The anatomy of the vocal organs may accordingly be discussed under three headings. The anatomy of respiration is concerned with the abdomen, thorax and trachea to the level of the larynx. Phonation and articulation are concerned with the region from below the larynx to the head. The passage from the larynx upwards is usually divided into three areas, viz., the laryngo-pharynx or larynx, the oropharynx and the nasopharynx. This passage may be closed to outside air in four regions by action respectively of the larynx, the velum, the tongue or the lips.

Respiration

§ 6·1. Respiration is essentially an automatic act that can be modified but not repressed by voluntary control. Accordingly the respiratory act for voice is a modified, often greatly altered, form of the primary mechanism. In primary silent breathing the respective periods of inspiration and

expiration are about equal. The volume of air passing in and out is about 500 c.c. (tidal air). A maximal inspiration is about an extra 1,500 c.c. (complemental air). A maximal expiration is an additional 1,500 c.c. (supplemental air). The residual air in the lungs after maximal expiration is about 900 c.c. The measure of vital capacity, averaging 3 litres, is used as a test of physical fitness.

Anatomy of the Thorax and Abdomen

§ 6·2. The thorax is supported by the rings of the twelve paired ribs and costal cartilages. These are articulated on the sternum and vertebral column. The diaphragm, which separates thorax from abdomen, is a double-domed tendon sheet, consisting of a central mass with the right dome higher than the left and coronal muscles running to the lower ribs, sternum and vertebral column. The abdomen contains the viscera with the liver on the right side and the stomach and spleen on the left side. The anterior wall of the abdomen is supported by strong muscles, running obliquely and vertically, which can compress strongly the viscera during defæcation, parturition or strong expiratory effort. An important part is played in respiration by the extension of the vertebral column. In the erect posture with the spine bent slightly back the greatest protrusion of the thorax comes at about the sixth rib. In this way the movement of the lower ribs has maximal effect in enlarging the thoracic volume.

Muscles

§ 6·3. (a) **Thorax.** 1. External intercostals. Running downward and forward from the lower border of one rib to the upper border of the next. Their action is to raise the ribs. They are innervated by the anterior divisions of the thoracic nerve.

2. Internal intercostals. Running downward and backward in the same way. Their action is probably to lower the ribs. They are innervated in the same way as the externals.

3. Triangularis sterni. Running from the cartilages of the 2nd to 7th ribs to the sternum. Contraction probably lowers the sternum in expiration. They are innervated by the thoracic nerves.

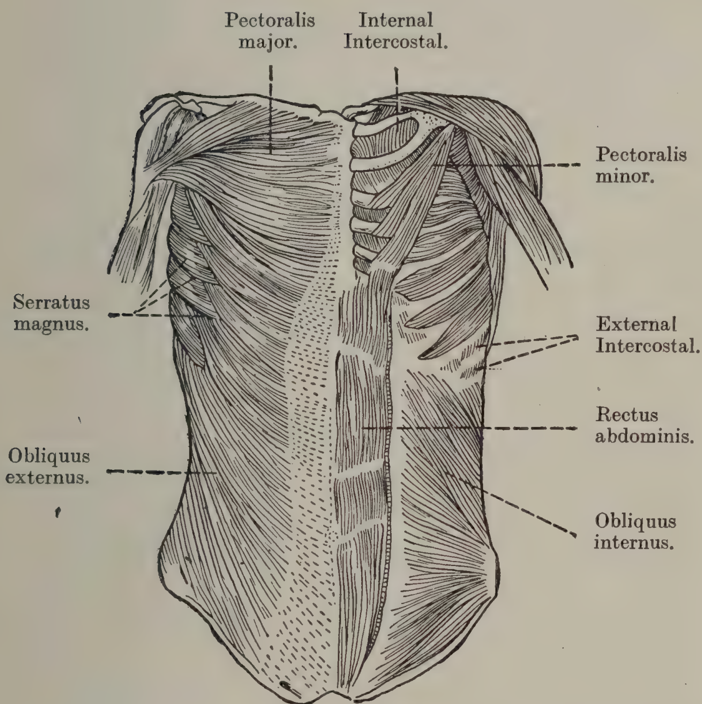

FIG. 3. The muscles of the thorax and abdomen. (Seth and Guthrie. (*By courtesy of the Oxford University Press.*)

4. Diaphragm. A coronal sheet of muscles running from the lower six ribs, sternum and lumbar vertebræ to the central tendon. The vertical displacement is about 2 cm. in quiet breathing, but in forced inspiration it may amount to 7·5 cm. These muscles are supplied by the 3rd to 5th cervical nerves.

§ 6·4. (b) **Abdominal.** 1. Rectus abdominis. A double muscle sheet running vertically downwards from the anterior surfaces of sternum and cartilages of the 5th to 7th ribs to be inserted by a strong tendon into the crest and symphysis of the pubis. Contraction acts to draw down the lower ribs or, if these are held fixed, to compress the viscera and raise intra-abdominal pressure. It is fed by the anterior thoracic nerves.

2. Obliquus muscles. Comprising :—

A. Obliquus externus, running transversely and downwards from the lower ribs to the crest of the ilium.

B. Obliquus internus, running in opposite direction and opposing the rotatory action of the externus.

C. Transversalis, the deepest muscle running horizontally from the cartilages of the lower ribs and the ilium to enter the ventral abdominal aponeurosis.

All three groups are paired muscles acting to compress the abdominal cavity. They are innervated by the anterior branch of the thoracic nerves.

Action of Respiration

§ 6·5. In the inspiratory phase of breathing the muscle action is as follows though not in the same order.

1. Wide opening of the glottal aperture to facilitate air intake.

2. Distension of the bronchioles.

3. Expansion of the thorax and lung volume in three dimensions :—

(*a*) From top to bottom by descent of the diaphragm. The main action.

(*b*) From back to front by upward and forward movement of the sternum due to the raising of the ribs.

(*c*) From side to side by upward and outward swinging of the 5th to 7th ribs.

In the expiratory phase the muscle action is as follows :—

1. Narrowing of the glottal aperture to conserve air pressure.

2. Contraction of the bronchioles.

3. Contraction of the thorax and lung volume.

(*a*) By ascent of the diaphragm in relaxation.

(*b*) By lowering of the sternum and ribs by relaxation.

(*c*) By dropping the lower ribs by relaxation and the pull of the abdominal muscles.

(*d*) Sometimes by abdominal compression forcing up the diaphragm.

§ 6·61. **Action of Respiration for Voice.** In the respiratory mechanism for voice these muscle acts are greatly altered. The inspiratory act is short and rapid while the expiratory act is prolonged and gradual. The volume of air passed is much greater, amounting to as much as 2 litres. The co-ordination of thoracic and diaphragmatic muscle tonus is disturbed, and in specialized training may be inhibited in favour of strong abdominal compression. The duration of expiration varies with the phrasing and intensity of the voice. The diversity of types prevents anything but a general consideration of the results of such studies as have been made in this connection. Schilling, **344.** Records of the circumferential measurement of thorax and abdomen can be made with the pneumograph. In this way the action of the various muscles may be deduced. Moreover, action currents may be recorded by electrical means from the muscles. The diaphragm movements may be shown by X-ray photography of the positions of viscera and lungs. A special method of recording these positions in a quasi-cinematographic way is called X-ray Kymography. Scott, **346.**

§ 6·62. Most commonly the muscle action of respiration for voice is an accentuation of the primary mechanism. The inspiratory act is short and the expiratory act prolonged. During expiration short inspiratory gulps may be taken at pauses in the flow of voice. The action is a co-ordinated thoracic and diaphragmatic movement. Russell, **242,** p. 191ff. However, under the influence of certain principles of training in elocution and singing the abdominal compression may play a greatly increased *rôle.* Curry, **273.** In this case the lower ribs are held expanded and elevated while expiration

is produced by abdominal compression forcing up the diaphragm from below, probably against the tonicity of the coronal muscles. Inspiration is produced by rapid relaxation of the abdominal muscles and rapid descent of the diaphragm. The explanation of the need for rib elevation and fixation is twofold. Firstly, the 5th to 7th ribs, forming the upper attachments of the abdominal muscles, must be held fixed in order that contraction of these muscles may compress the abdomen. Secondly, the tonicity of the thoracic muscles would be accompanied by a conditioned tension of the diaphragm, producing antagonism to the upward force of the abdominal compression. The antagonism of these two forces provides a variable adjustment of expiration much more delicate than the simple relaxatory collapse of the thorax. The volume of air passed must not be increased to the point of upsetting this delicate balance. The practice of taking a deep breath before phonation often results in a faulty inception of voice. Many individuals make use of much less than the 2 litres of air during phonation. The volume of air does not bear a close relationship to the intensity of the voice. However, it is found that in general singers have a slightly larger lung capacity than the average. Nadoleczny, **237**. The major factor is the efficiency of conversion of breath pressure into voice intensity.

§ 6·7. A momentary disruption or arrest of respiration may occur during strong muscle action with the upper extremities, or during abdominal pressure in defæcation, parturition and so on. In these cases the glottis is closed to prevent air escape and the expanded thorax assists as a fixed support of the muscles involved : pectoralis, serratus magnus, rectus abdominis, etc. During apnœa, or gasping for breath, when the individual grasps a support, the muscles of the shoulder, neck and face may take part in the inspiratory effort. A similar use of an external support for the shoulder and thoracic muscles is to be noted in the habit of the Moslem muezzin, who frequently grasps the balcony rail of the minaret with both hands while voicing as loudly as possible

the call to prayer. Any attempt to raise the clavicular bones and upper ribs is frequently a sign of the untrained pupil in singing. This attempt to enlarge the thoracic cavity is unwise, since movement at this region cannot enlarge the cavity materially.

Phonation

§ 7·1. While the initial force of the sound waves described as voice is derived from the air stream expelled from the lungs, the conversion of the steady outward flow of air into a periodic, interrupted, audible movement is effected by vibration of the vocal cords.

§ 7·2. **The Anatomy of the Larynx.** The supporting framework of the larynx is composed of three structures: two cartilages, the cricoid and the thyroid, and the hyoid bone. The lower cartilage—the cricoid, or 'ring' cartilage—is continuous and circular, much higher at the back than at the front, and forms the basis of the larynx. The upper thyroid, or 'shield' cartilage, is incomplete and open at the back where the larynx joins with the œsophageal wall. The thyroid is articulated on the posterior cornuæ of the cricoid and the pivoting action is effected mainly by action of the cricothyroid muscle. If the cricoid is held fixed by the infralaryngeal muscles, the anterior notch of the thyroid is drawn down and the thyroid pivots and slides on the cricoid. If the thyroid is held fixed by the supralaryngeal muscles, the cricoid is drawn upward in the neck. This, the more frequent action, is part of the bodily upward movement of the larynx observed during the production of high pitches of voice, or during swallowing. The articulation is of a complex form so that a good deal of sliding as well as rotatory movement may take place. The hyoid bone is an U-shaped, unattached bone in intimate relationship with the larynx. It has a central body and a pair of greater and lesser horns and carries the attachments of many muscles. The bone may be grasped and moved in the neck. It is drawn up and forward to the lower mandibular edge during the ascent of

the larynx. The internal structure of the larynx is supported by certain small cartilages of a pyramid or boomerang shape. These twin, four-sided, arytenoid cartilages are articulated on the superior posterior face of the cricoid and carry insertions

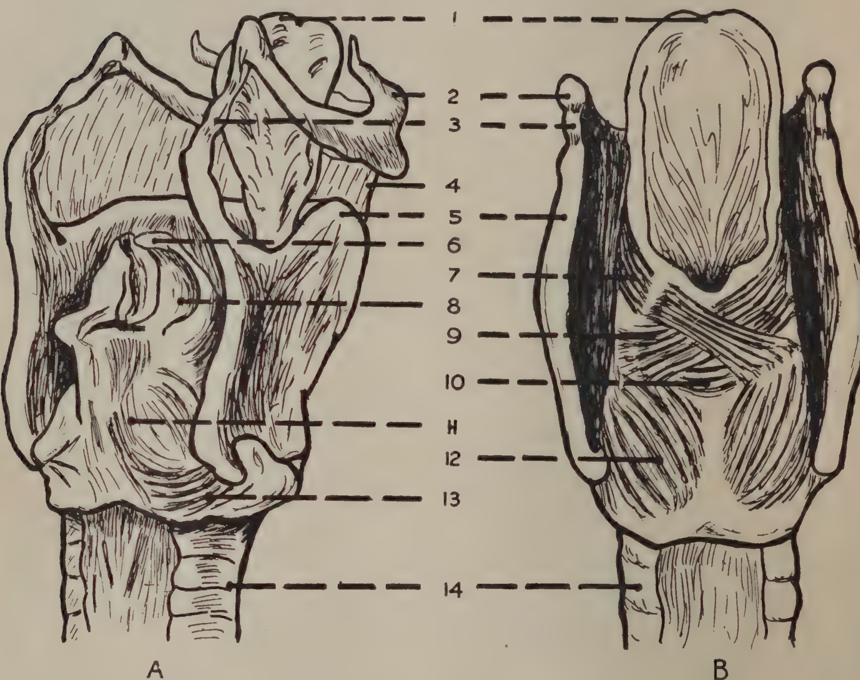

FIG. 4. A. Oblique view of dissected larynx cartilages. B. Posterior view of larynx muscles. 1. Epiglottis. 2. Hyoid bone. 3. Cartilago triticea. 4. Thyrohyoid membrane. 5. Thyroid cartilage. 6. Cartilage of Santorini. 7. Aryepiglottic muscle. 8. Arytenoid cartilage. 9. Transverse arytenoid muscle. 10. Horizontal arytenoid muscle. 11. Cricoid cartilage. 12. Posterior cricoarytenoid muscle. 13. Cricothyroid ligament. 14. Trachea.

of several paired and one single muscle. The shape of the arytenoid cartilage indicates the various rotatory and sliding motions which it performs under the pull of the internal laryngeal muscles. The cartilages form the posterior attach-

ments of the twin thyroarytenoid muscles, which with their covering of tissue and ligament constitute the wedge-shaped projections into the lumen of the trachea called the vocal cords or vocal lips. Certain additional vestigeal cartilages —the cartilages of Wrisberg and Santorini—form supporting structures in the folds of tissue joining the arytenoids and larynx wall to the epiglottis and pharynx. The epiglottis is also supported by a cartilage with a closely attached thyro-epiglottic ligament joining into the angle of the thyroid just below the notch. Another bundle of elastic tissue may be considered to constitute a hyoepiglottic ligament running from the upper border of the hyoid.

§ 7·3. **Muscles of the Larynx** (including the hyoid bone). The muscles of the larynx may be considered in four groups :—

A. The internal larynx muscles—innervated by the recurrent or inferior laryngeal nerve.

B. The cricothyroid muscle—innervated by the superior laryngeal branch of the vagus nerve.

C. The muscles linking the larynx and hyoid bone with other structures above and below the larynx, including the constrictors of the pharynx.

D. The stylopharyngeus system, comprising the stylo-pharyngeus, palatopharyngeus, arytenoid obliquus and aryepiglottic muscles. These with the help of the crico-thyroid constitute an auxiliary mechanism producing ventricular band voice in cases of dysfunction or pathology of the vocal cords. Réthi, **331–5**.

§ 7·4. A. *The Internal Muscles of the Larynx.* Inasmuch as the primary function of the larynx was to close the trachea in a valvular fashion, the internal muscles of the larynx may be considered according to their function as abductors or adductors of the glottis.

1. *Abductors.* The only muscle is the twin cricoarytenoid posticus, which arises from the posterior face of the cricoid and is inserted into the outward aspect of the arytenoid. By pulling on the outer parts of the arytenoids they separate them and swing open the glottis. During phonation they

brace back the arytenoids against the pull of the tensed thyroarytenoid and cricothyroid muscles. In antagonism to the lateral cricoarytenoids they produce a state of variable balance of the glottal aperture as in laboured breathing or the sound [h]. Russell, **242,** p. 244.

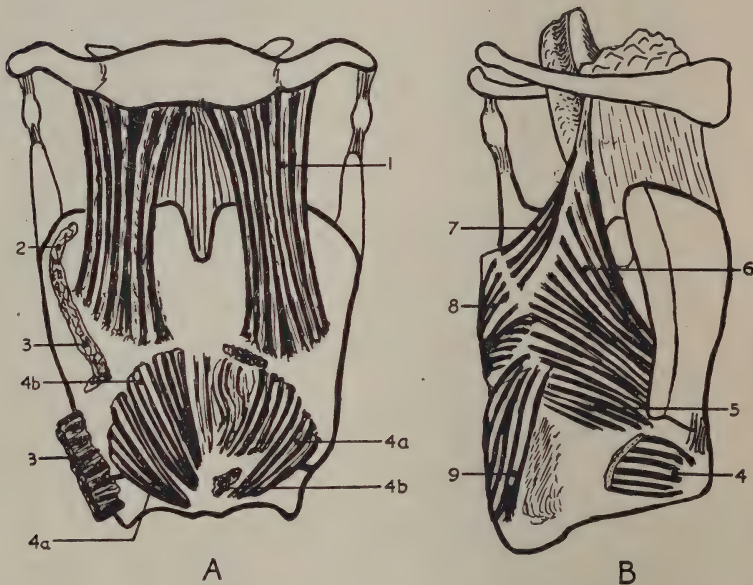

FIG. 5. A. Anterior view of larynx muscles. B. Side view of internal muscles (thyroid ala cut.). 1. Thyrohyoid. 2. Palatopharyngeus. 3. Laryngopharyngeus (cut.). 4*a*. Cricothyroid oblique. 4*b*. Cricothyroid rectus. 5. Lateral cricoarytenoid. 6. Thyroarytenoid externus. 7. Aryepiglottis. 8. Arytenoid. 9. Cricoarytenoid posticus.

2. *Adductors.* (i) The cricoarytenoid lateralis. A paired muscle which arises from the lateral part of the cricoid and is inserted in the front of the muscular process of the arytenoid. It is fed by the inferior laryngeal nerve and acts to pull the arytenoid forward, thereby bringing the vocal cord nearer to the midline.

(ii) The interarytenoid muscle. This runs transversely

between the hollows on the posterior surfaces of the arytenoids. There are usually two parts: firstly, a superficial, oblique part, which is formed by two bands of fibres crossing over each other. The second part is a transverse, horizontal band linking the cartilages. Some fibres are

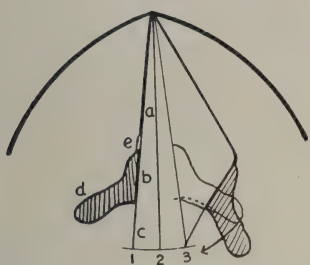

FIG. 6. The degrees of glottal opening. *a.* The vocal ligament. *b.* The mesial surface of the arytenoid cartilage. *c.* The cricoarytenoid ligament. *d.* The arytenoid cartilage. *e.* The tip of the vocal process. 1. The rest and cadaveric position. 2. The position for phonation. 3. The position for deep inspiration.

prolonged into the aryepiglottic fold as the aryepiglottic muscle. The interarytenoid is fed by the inferior laryngeal nerve and acts to slide together the arytenoids and close the glottis, thereby approximating the vocal cords. The oblique part probably acts to pull together the upper tips of the cartilages and also to approximate the ventricular bands.

(iii) The thyroarytenoid muscle. This is a paired muscle of variable and complex structure arising from the inner surface of the thyroid cartilage at the notch and inserted into the vocal process of the arytenoid. The muscle is usually formed of two parts: an inner which forms the support of the vocal cord, and an outer which extends up between the inner part and the thyroid and sends fibres into the ventricular bands. It is claimed that careful dissection can show the existence of six fasciculi in the muscle, all of which have different origins, insertions and actions. Josephson, **297**. Moreover, many anatomists have stated the existence of

careful dissections, showing fibres diverging from the body of the muscle and inserted into the ligamentous edge of the cord at an angle to the horizontal run of the main fibre bundles. These are called the aryvocalis muscle. Strong, **360**. The external part of the muscle runs generally downward and backwards from the inner superior aspect of the thyroid to the vocal process, thereby crossing the internal fibres almost at right angles. It is possible that this part acts to approximate the ventricular bands in certain modes of voice. Russell, **242**, p. 224ff. The muscle is innervated by the inferior laryngeal nerve and acts to tense the vocal cords and so produce voice.

§ 7·5. B. *The Cricothyroid Muscle.* By reason of the innervation of this muscle by the superior laryngeal nerve as well as the fact that contraction of this muscle plays a major part in the production of all types of voice, it is important to consider it separately from the other external muscles. It is a paired muscle running from the anterior ring of the cricoid to the underbody and inferior horns of the thyroid. It is usually separated into a superficial horizontal part and a deep vertical part. The horizontal part probably acts to pull the posterior end of the thyroid forward to the cricoid or *vice versâ*, depending upon which cartilage is fixed by other muscles. The vertical part acts to approximate the anterior arch of the cricoid and the front body of the thyroid by movement of whichever cartilage is not fixed by other muscles. A divergent part of the external fibres may occur as a posterior ceratocricoid muscle running from the back of the cricoid upward and outward to the internal aspect of the inferior horn of the thyroid. The precise anatomy of the muscle is variable. In general the muscle acts as antagonist to any muscles that act to tense the vocal cord. The main action is to tilt down the anterior part of the thyroid, thereby lowering and elongating the vocal cord by about 3 mm. When the vocal cords are tensed in phonation, the cricothyroids hold the anterior attachment fixed in antagonism to the pull of the posticus muscles. Némai, **322–3**.

§ 7·61. C. *Muscles relating the Larynx to other Structures.* A. Supralaryngeal muscles, linking with structures higher than the larynx.

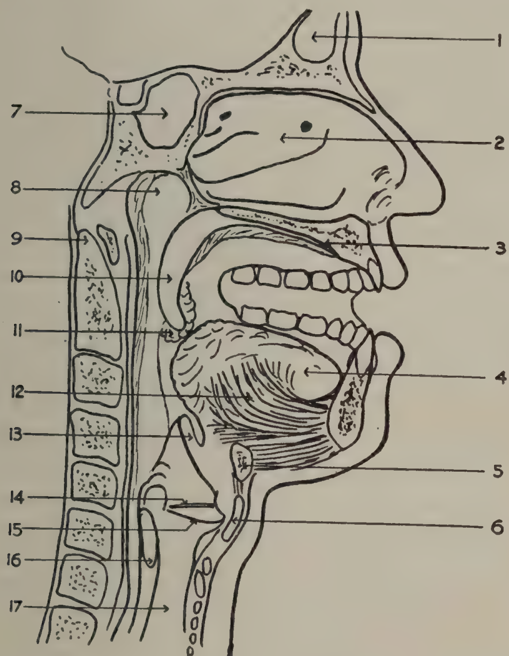

FIG. 7. A mesial, sagittal section of the head and neck. 1. Frontal sinus. 2. Nasopharynx with turbinated bones. 3. Hard palate. 4. Tongue. 5. Hyoid bone. 6. Thyroid cartilage. 7. Sphenoidal sinus. 8. Rhinopharynx. 9. Cervical vertebræ. 10. Velum and uvula. 11. Pharyngeal tonsil. 12. Genioglossus muscle. 13. Epiglottis. 14. Ventricular band. 15. Vocal cord. 16. Cricoid cartilage. 17. Trachea.

(i) The thyrohyoid muscle. A paired muscle running from the oblique line of the thyroid to the body and greater horn of the hyoid. It is supplied by fibres of the 1st and 2nd cervical nerves from what is probably a branch of the hypoglossal. It acts to draw the hyoid down, or, if that is fixed, to draw the larynx upward.

(ii) The geniohyoid muscle. A paired muscle sheet arising from the ridge extending round each half of the mandible and passing inward to join in a central fibrous raphe common to each muscle. The posterior fibres are inserted into the body of the hyoid. It is innervated by the mandibular part of the 5th nerve and acts to draw the hyoid forward and raise the floor of the mouth, elevating the tongue towards the palate.

(iii) Digastric (anterior belly). A paired muscle running from the inner anterior part of the mandible to a tendon which is bound down to the greater horn and body of the hyoid. It is fed by the mandibular part of the 5th nerve and acts to raise the hyoid and elevate the floor of the mouth.

The geniohyoid, mylohyoid and digastric muscles assist in the lowering of the mandible when the hyoid is fixed by infralaryngeal muscles, such as the sternohyoid and sternothyroid.

(iv) The stylohyoid muscle. A paired muscle running from the upper part of the styloid process to the base of the greater horn of the hyoid. It is supplied by the digastric branch of the 7th nerve and acts to raise and draw back the hyoid.

§ 7·62. B. The infralaryngeal muscles, linking with structures below the larynx.

(i) The sternohyoid muscle. A band of fibres running from the manubrium sterni and the clavicle to the lower border of the hyoid body. It is supplied from the 1st to 3rd cervical nerves through a descending branch of the hypoglossal, which forms a plexus with the descending cervical nerves. It acts to draw the hyoid downwards.

(ii) The sternothyroid muscle. A band-like muscle running from the sternum and the cartilages of the 1st and 2nd ribs to the oblique line of the thyroid. It is fed as for the sternohyoid and acts to draw the thyroid down.

(iii) The omohyoid muscle. This is a long flat muscle formed of two bellies: the inferior, running from the scapula to an intermediate tendon, and the superior, running from this tendon to the lower border of the hyoid. It is supplied as for the sternohyoid and acts to draw the hyoid down.

The sternohyoid and sternothyroid assist the cricothyroid in elongating the vocal cord in phonation. Némai, **323**.

§ 7·63. C. The constrictors of the pharynx.

(i) The inferior, middle and superior constrictors, which overlap one another from below upwards. These are paired muscle sheets joining together in a median raphe, extending almost the entire length of the posterior pharynx wall. The superior constrictor covers the area from the level of the mastoid process to the root of the tongue. The middle constrictor, which overlaps the superior, covers the region of the hyoid. The inferior constrictor, which overlaps the middle, covers the region of the larynx. These muscles are innervated from the pharyngeal plexus, the inferior probably receiving fibres from the inferior laryngeal nerve. They act to decrease the pharynx volume, probably slightly elevating the larynx at the same time.

(ii) The palatopharyngeus muscle. A paired muscle of complex origin from the hard palate and passing with the stylopharyngeus down the posterior pillar of the pharynx to be inserted into the upper thyroid and then in a fan-shape into the mucous membrane of the posterior pharynx. It is innervated from the pharyngeal plexus and acts to fix the larynx in position, especially during ventricular band voice. Réthi, **332**.

§ 7·7. D. *The Stylopharyngeus System.*

The stylopharyngeus muscle, which runs from the base of the styloid process to pass then under the pharynx constrictors and terminate in a fan-shape in the posterior wall of the pharynx, while sending some fibres into the posterior thyroid alæ. It may join with the palatopharyngeus and also send fibres from the thyroid division into the epiglottis in conjunction with the aryepiglottis muscle. It is innervated by a branch of the glossopharyngeal nerve and acts normally to constrict the larynx aditus. It may act to tip down the thyroid by pulling on the posterior tips. Russell, **242**, p. 207. In cases of dysfunction or pathology of the vocal cords the stylopharyngeus system, with the

assistance of the aryepiglottis and oblique interarytenoid muscles, constitutes a substitution mechanism whereby the ventricular bands are approximated over the vocal cords to produce ventricular band voice (Taschenbandstimme). Réthi, **333–4.** This abnormal voice is harsh and lower-pitched in comparison with the normal. Co-ordination is effected by the fact that fibres from the inferior laryngeal nerve, which pass from the oblique muscle to the aryepiglottis, may enter the stylopharyngeus. The glossopharyngeal nerve sends a branch to the pharyngeal plexus. Anæsthesia of the stylopharyngeus eliminates the substitution voice. Réthi, **333.**

Innervation of the Larynx

§ 7·81. The larynx is innervated in complex fashion from branches of the vagus or 10th nerve. The vagus, which is a mixed sensory and motor nerve, has two ganglia—the root and the trunk ganglia. The motor fibres arise in the medulla in the dorsal nucleus and the nucleus ambiguus in common with the 7th, 9th and 11th cranial nerves. The sensory fibres terminate mainly in the fasciculus solitarius and the dorsal nucleus in conjunction with fibres from the 9th nerve. The branches of the vagus arise from the trunk ganglion and consist of two well-defined branches—the superior laryngeal nerve, given off near the sternothyroid muscle and the thyroid cartilage ; and the inferior laryngeal nerve, given off in the neck near the subclavian or aortic arteries on right and left sides respectively, and passing up and behind these arteries to enter the larynx by piercing the inferior constrictor muscle. Within the skull the vagus receives no accessory fibres and may be called the ‘ Ur-vagus ’ or primitive vagus. Réthi, **335.** After passing the foramen jugulare the vagus receives anastomoses from the accessory, hypoglossal and often the glossopharyngeal nerves. A less well-defined branch of the vagus joins with fibres from the 9th nerve in the pharyngeal plexus, which also receives a branch from the superior laryngeal nerve, and may send a branch—the middle laryngeal nerve—to the cricothyroid

muscle and the larynx mucosa. Exner, 387. There may be branches from the vagus which join with the sympathetic nerve. Réthi, 335. The superior laryngeal nerve divides

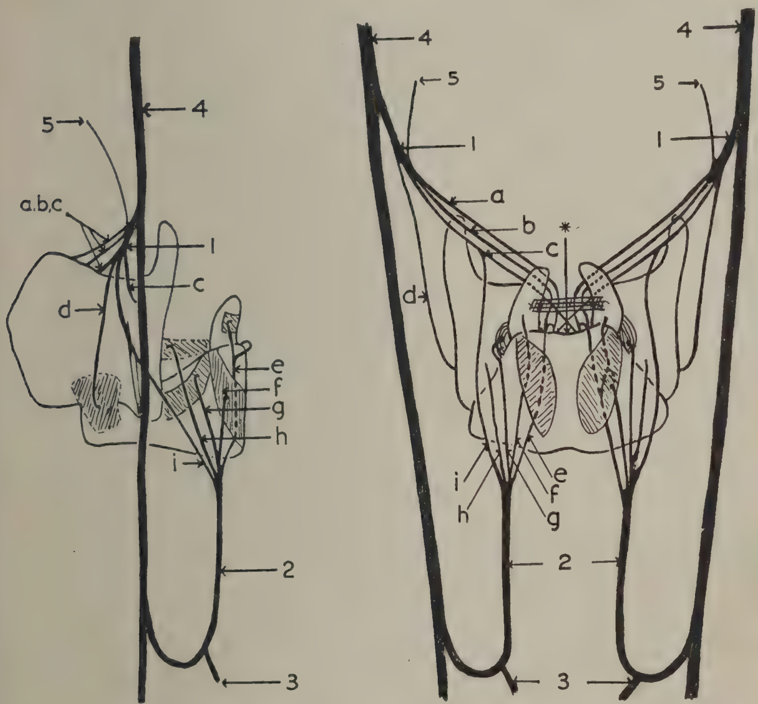

Fig. 8. The motor and sensory innervation of the larynx* (Onodi). 1. Superior laryngeal nerve and branches. *a*, *b*, *c*. Internal branches to mucous membrane. *d*. External branch to cricothyroid muscle. 2. Inferior laryngeal nerve and branches. *e*. To transverse arytenoid muscle. *f*. To posterior cricoarytenoid muscle. *g*. To lateral cricoarytenoid muscle. *h*. To thyroarytenoid muscle. *i*. Ramus communicans or the anastomosis of Galen. 3. Twigs to sympathetic and cardiac nerves. 4. Main body of vagus nerve. 5. Twigs to sympathetic nerves. * Crossing over of sensory fibres.

into two branches—the external branch, which is generally small and runs near to the thyroid attachment of the sterno-thyroid muscle to pass round the inferior tubercle of the

thyroid and enter the cricothyroid muscle on its superficial aspect. As this nerve passes deep to the inferior constrictor muscle it gives off a twig to this muscle as well as occasionally a few filaments which join with the inferior laryngeal nerve as it passes over the lateralis muscle. The second branch of the superior nerve is the internal branch, which enters the larynx through the thyrohyoid membrane and divides there into two main twigs. These twigs supply the mucous membrane of larynx, epiglottis and lower pharynx. The larger twig inserts by subsidiary filaments into the mucosa of the lateral pharynx wall, glossoepiglottic fold, base of the epiglottis, the vestibule of the larynx and the anterior surface of the epiglottis near the attachments of thyroarytenoid and thyroepiglottic muscles. The smaller twig runs down in the mesial wall of the sinus pyriformis, giving off two or three filaments to the muscles of the aryteno-epiglottis fold, the mucous membrane and the glands on the posterior surface of the arytenoid cartilages, where it often gives off one or two branches to the inter-arytenoid muscle, where it may join the branch to this muscle from the inferior laryngeal nerve. It is continued down on the posterior posticus muscle, giving off filaments to the mucosa, and finally joins with an ascending branch of the inferior laryngeal nerve in the so-called anastomosis of Galen. This appears to be a continuous nerve, which may be the original strand of fibres separated from the vagus, from which the further fibres of the laryngeal nerves were formed. Dilworth, **191**.

§ 7·82. The inferior laryngeal nerve sends off four branches —firstly, the cardiac branch, which enters the deep cardiac plexus. The second is that to the trachea and the œsophagus, and near this branch the nerve may give two twigs which go to the thyroid gland and also to the œsophagus. About an inch from the larynx wall the nerve divides into two branches, the smaller of which joins with the internal branch of the superior nerve, as described above. It enters the larynx by piercing the inferior constrictor muscle. The larger division runs upwards at the lateral part of the posticus

muscle, to which it gives off the first twig. The second twig goes to the interarytenoid muscle, where it is often joined by a twig coming from the main part of the inferior laryngeal nerve and joining to the twig from the internal, superior nerve. The inferior laryngeal nerve then follows the superficial surface of the lateralis muscle, to which it gives off fine twigs and it ends by sinking into the thyroarytenoid muscle. It may here be joined by a twig from the internal branch of the superior nerve. There seem to be two main ways of considering the innervation of the larynx. The classical school considers that the superior and inferior nerves are separate sensory and motor nerves, respectively. The school of Exner considers that they are mixed sensory and motor and that each muscle receives a double nerve supply. Réthi, **335**. There is an obvious middle way of considering that the nerves are mixed, but that there is no complete double innervation. In this view the laryngeal nerves are really a plexus of a highly modified structure, which was formed originally by a separation of a strand of fibres to the larynx from the body of the vagus. This is represented by the common branch of superior and inferior nerves, called the ramus communicans, and the separation of further nerves from this ramus produced the complicated laryngeal innervation. Dilworth, **191**.

§ 7·83. The course of the left inferior laryngeal nerve is often longer than that of the right, since the right nerve lies more anteriorly on the trachea. The left nerve is therefore more liable to damage or pressure from local aneurisms of the aorta or the thyroid gland. This may account for the frequent paresis of the left vocal cord. Burger, **263**. There is a remarkable tendency for the sensory fibres to cross the median line so that regions are reached from both sides. The mucosa is richly supplied with sensory fibres to the superior laryngeal nerve and the anastomosis of Galen. The vocal cord area may be fed by sensory fibres from the inferior laryngeal nerve. The chronaxia of the inferior laryngeal is about ·1 mu. Accordingly, the internal laryngeal muscles

are probably the fastest working of the skeletal muscles. Campos, Chauchard, **266**, p. 393. The sensory fibres end in free terminations and subepithelial arborizations. There may be special end organs of columnar cells and free nerve endings in the vocal cords. Sunder-Plassman, **326**.

§ 7·84. The mucous membrane of the larynx is mainly thick with subadjacent areolar tissue save over the cartilages or the thyroarytenoid ligament, where it is thin and closely adherent. The epithelial covering is stratified, ciliated, columnar type throughout save for that over the edges of the vocal cords and ventricular bands, which is of the stratified, squamous type. Mucous cells and glands are plentiful, especially in the epiglottis, ventricles and ventricular bands, and to within 3 mm. of the free edge of the vocal cords. The abrupt change to squamous epithelium over the edges of the cords and bands indicates the vibratory contact of these areas, and in the vocal cords this area is the seat of the fibrous thickening and multiplication of epithelial layers, forming the so-called singer's vocal cord ' nodule.'

§ 7·85. The pharyngeal plexus is an important structure, which contains one or more minute sympathetic ganglia, and ramifies over the middle constrictor of the pharynx. It supplies motor fibres to the constrictors of the pharynx and to the muscles of the soft palate, with the exception of the stylopharyngeus and the tensor palati. It receives sensory fibres from the mucosa of the pharynx. A filament from the plexus—the lingual branch of the vagus—unites fibres from the 9th and 10th nerves and joins the hypoglossal nerve as it hooks around the occipital artery. The plexus is formed of the following branches: the pharyngeal branch of the superior cervical ganglion, the pharyngeal branch of the petrous ganglion of the 6th nerve, a branch from the superior laryngeal nerve and the middle laryngeal nerve.

The Action of the Larynx

§ 7·91. A coronal section of the larynx shows in detail the shape of the larynx walls. The free passage of air from below

is restricted first at the wedge-shaped projections of muscle and ligamentous membrane called the true vocal cords. It will be noted that these in no way resemble a cord of any description, and it is unfortunate that the term 'vocal cord' has become so popular and yet so misleading. Above the

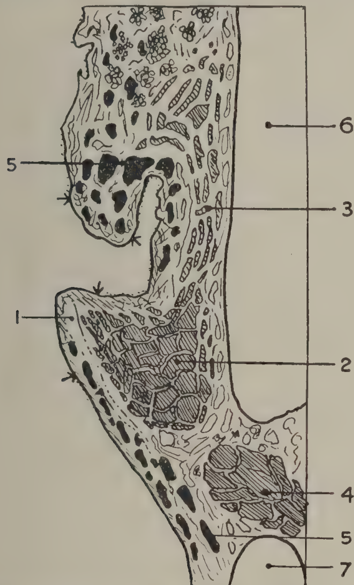

Fig. 9. A frontal, vertical section of the right vocal cord, near the middle (male adult). 1. Elastic ligament. 2. Thyroarytenoid muscle. 3. Fibres of external thyroarytenoid muscle continued into ventricle. 4. Lateral cricoarytenoid muscle. 5. Glands. 6. Thyroid cartilage. 7. Cricoid cartilage. The areas between the arrows are covered with squamous epithelium ; the rest is the ciliated, columnar type.

cords the larynx walls recede to form a pouch or ventricle, the dimensions of which are greatly variable. The ventricle is much larger in the greater apes, often taking the form of a pouch extending down behind the trachea and serving as a reservoir of air when the glottis is closed during strong action. Above this, again, the walls project in the false cords or ventricular bands composed of soft tissue and the fibres of

the external thyroarytenoid muscle and closed together largely by action of the stylopharyngeus muscle. From this point the larynx merges into the pharynx and joins with the epiglottis and the œsophagus.

§ 7·92. The aperture of the glottis varies according to the action of the larynx. For non-vocal breathing in the inspiratory period the glottal aperture is widened in proportion with the depth and rapidity of inspiration. Negus, **238,** p. 121. The widening is effected by action of the posterior cricoarytenoids, which swing round the arytenoids and also slide them apart. In the expiratory period the aperture is narrowed to prevent too sudden deflation of the lung. In some muscular actions the glottal narrowing is increased to produce closure of the glottis. Thus during strong action of the pectoral or abdominal muscles the glottis may be closed to produce increased thoracic air-pressure by thoracic fixation or rigidity. Other involuntary reflex actions such as coughing, sneezing, hiccup, sobbing, sighing and laughing are produced with some type of sudden glottal closure and/or opening. In coughing and sneezing the glottis closes and opens suddenly to force a burst of air through mouth or nose in an attempt to relieve irritation of the mucous membrane in those regions. Russell, **242,** p. 237. Laughing is produced by a jerky expiration frequently accompanied by phonation of a consonant and vowel [ha ha]. The expiratory stroke in laughing is mainly effected by abdominal contraction. Hiccup, sobbing and sighing are forms of staccato or convulsive inspiration arrested by glottal closure and probably aroused respectively by gastric irritation, emotional unrest and venosity of the blood through inaction. In coughing the air may often pass out also by the nose. Imhofer, **387,** p. 1286. In these actions there is usually sphincteric closure of the larynx involving approximation of vocal cords and ventricular bands, and they are carried over into phonation in the form of the glottal stop [ʔ], produced by a sudden explosive opening of the glottis. In the inspiratory position the opening of the glottis is about 12 mm., while in the

cadaveric position the glottis assumes a median opening of about 5 mm.

§ 7·93. In phonation the action of the larynx is variable and complex. In whispered speech the glottis is narrowed enough to produce audible air friction and even perhaps to the point at which the edges of the cords vibrate. Negus, **238**, p. 441. Moreover, in whisper the width of the aperture between the arytenoids varies according to the type of speech-sound, being widest during the explosive stage of a stop consonant when an increased air pressure is produced in the pharynx. Rousselot, **117**, I, p. 469. In normal voiced speech the vocal cords are closed together to meet in the midline, and the vibratory motion takes the form of horizontal displacement with a slight vertical component and a recoil to the midline position. The most detailed study of the anatomical structure of the thyroarytenoid muscle has shown the possibility of considerable manipulation of the ventricular bands and the ventricle. Josephson, **297**. The six fasciculi of the muscle consist of: firstly, the horizontal part, which is the true vocalis muscle, running from the anterior commissure and angle of the thyroid and inserted into the top of the vocal process of the arytenoid. It acts to approximate and tense the cords. The second is the inner oblique, running from the inner lower surface of the thyroid at 45 degrees to the vocal process. It acts to draw the arytenoids down, inward and forward. The third part, the middle oblique, arises from the inner lower third of the thyroid and passes at about 35 degrees to curve over the vocal process and insert into the outer border and external surface of the arytenoid. Some fibres run to the ventricle and the false cords. It acts to rotate the vocal process outward, deepen the floor of the ventricle and draw down and evert the false cords. The fourth, the external oblique, arises from the inner upper third of the thyroid and runs upward at 65 degrees to the upper false cord. It pulls the false cord down and everts it. The fifth part, the transverse part, arises from the thyroid above the false cords and spreads fanwise in the

mucosa of the false cord and the ventricular ligament. It acts to elevate and retract the false cords. The sixth part, the superior oblique, arises from the thyroepiglottic ligament at the base of the epiglottis and passes down to be inserted into the false cord at the base of the arytenoid. This is probably closely linked with the aryepiglottic muscle. It acts to draw forward and upward the false cords and contract them vertically.

§ 7·94. There is no doubt about the source of phonation in the larynx, despite the desire of certain theorists to deny this and attribute phonation to action of the paranasal sinuses. White, **253** ; Wheeler, **397**. Difference of opinion centres upon the more detailed considerations of laryngeal action for specific speech-sounds or qualities of voice. It is probable that the whole larynx participates in the production of any given sound, and laryngoscopic studies have shown the constantly changing laryngeal actions in singing and speech. Sounds made with a freshly excised larynx approximate nearest to the laryngeal sound in the human living larynx. A. G. Bell, **135**. It is probable that the vowel [a], produced with a harsh quality of voice, approximates most nearly to this larynx sound. Trendelenburg, **382** ; Russell, **242**, p. 102. The alterations in the larynx sound produced by the articulatory mechanism and the evidence available concerning these changes are studied in Chapter III. It is generally considered also that the maximum intensity of sound vibration is produced at the larynx, and that the cavities of the oropharynx and nasopharynx act to modify the quality and increase the flow of energy from the source, thereby increasing the loudness of the sound. Pathological results of over-intense phonation are invariably produced in the larynx, usually as acute inflammation of the mucous membrane or the vocal cord nodule. Far from being a simple or pure tone, the larynx sound is complex and variable. A great measure of the quality characteristic of a given voice is present in the original larynx sound, as dissociated from the modifying influences of the articulatory speech organs.

Thus the movements performed by the larynx vary continuously from moment to moment, and this is confirmed many times in observation. By reason of the supposition of the more radical importance of the articulatory movements in producing voice quality, the larynx action has often been assumed to be static and invariable for all forms of vocal product. Thus the classification of speech-sounds is based upon this assumption.

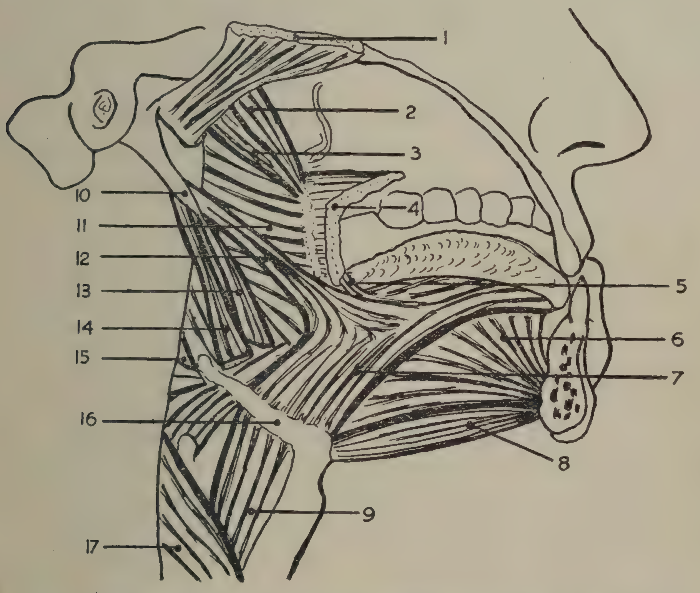

Fig. 10. The pharynx and extrinsic lingual muscles. 1. Stump of masseter. 2. Tensor palati. 3. Levator palati. 4. Buccinator (cut.). 5. Palatoglossus. 6. Genioglossus. 7. Hyoglossus. 8. Geniohyoid. 9. Thyrohyoid. 10. Styloid process. 11. Superior constrictor. 12. Styloglossus. 13. Stylopharyngeus. 14. Stylohyoid (cut.). 15. Middle constrictor. 16. Hyoid bone. 17. Inferior constrictor.

Articulation

§ 8·11. The mechanism of articulation is concerned with the regions of the oropharynx and nasopharynx and with

the actions of the tongue, soft palate, lips and lower jaw. The anatomy of these regions is as follows.

§ 8·12. *Tongue.* I. Extrinsic muscles running from the skull or hyoid bone to the tongue.

1. The genio-glossus muscle, which runs from the posterior base of the lower jaw in a spreading fan-shape to be inserted into the whole tongue from the tip to the root. The muscle is innervated by the hypoglossal nerve, and the complex action includes retraction of the tongue by the anterior fibres, drawing forward and protrusion by the posterior fibres and depression, with increased concavity of the dorsum by the middle part.

2. The hyoglossus muscle, which runs from the hyoid bone to the sides of the tongue. It is fed by the hypoglossal nerve and acts to depress the sides of the tongue, as well as retracting the protruded tongue.

3. The styloglossus muscle. This runs from the styloid process to the outer sides of the tongue and continues longitudinally. It is supplied by the hypoglossal nerve and acts to retract the tongue and elevate the sides, thereby producing transverse concavity of the dorsum.

4. The palatoglossus muscle, which runs from the anterior palate and in the anterior faucial pillar to the tongue. It is supplied from the pharyngeal plexus and acts to elevate the tongue, depress the soft palate and in conjunction with the palatopharyngeus to constrict the pharynx.

II. Intrinsic muscles of the tongue, all supplied by the hypoglossal nerve.

1. Lingualis. Longitudinal fibres in the tongue.
2. Transversus. Transverse fibres.
3. Perpendicularis. A few scanty vertical fibres.

These muscles act mainly as accessories to the external muscles. They turn the tip of the tongue in any direction or perhaps retract the tongue after protrusion. They may act to make rigid the surface of the tongue.

§ 8·2. *Soft Palate and Uvula.* This is a fold of mucous membrane, continuous with the hard palate, enveloping

several layers of muscle fibres, and ending in the uvula, which may be of variable length. Two fibrous folds, the faucial pillars containing muscle bundles, run downwards from the palate on each side. These contain the palatoglossus muscle in the anterior pillar and the palatopharyngeus in the posterior pillar. Both muscles act as important constrictors of the oropharynx. The deep recess between these pillars contains the faucial tonsil. Injury to these muscles during tonsillectomy may cause some difficulty in action of these constrictors. The muscles working to elevate the soft palate act as follows. The levator palati, and azygos muscles, innervated from the pharyngeal plexus, raise the soft palate and uvula and press these against the aperture of the nasopharynx. This is really a sphincteric action, because the constrictor muscles of the pharynx act to compress this area and raise an eminence on the posterior wall of the pharynx called Passavant's cushion, against which the uvula is pressed. Negus, 238, p. 410.

§ 8·3. *Lips.* The major action of the lips in articulation takes the form of protrusion, retraction, approximation, closure and distension. Most of the action of closure or opening is a consequence of the movement up or down of the lower jaw. However, certain facial muscles are prolonged to form a strong, elliptical muscle, which encircles the lips and is called the orbicularis oris. It is fed by the facial nerve, and acts to bring the lips together, close the mouth and press the lips against the teeth. Its more peripheral fibres act to protrude the lips. The other facial muscles contribute to the expression of meaning in facial movement, and their names are quite descriptive of their action.

§ 8·4. *Lower Jaw.* The major action of the lower jaw in articulation is a closing or opening movement of the mouth, save that for the consonants [f, v] the lower jaw is retracted and closed, thus pressing the upper teeth upon the surface of the lower lip. The major muscles effecting closure are the masseter and temporalis, and, since the grinding masticatory movements involve retraction and advancement

as well as closure, these muscles are capable also of some degree of retraction and advancement of the lower jaw. They are innervated by the mandibular division of the 5th nerve. The muscles acting to depress the lower jaw and open the mouth are the geniohyoid, mylohyoid and digastric muscles, linking the jaw with the hyoid bone.

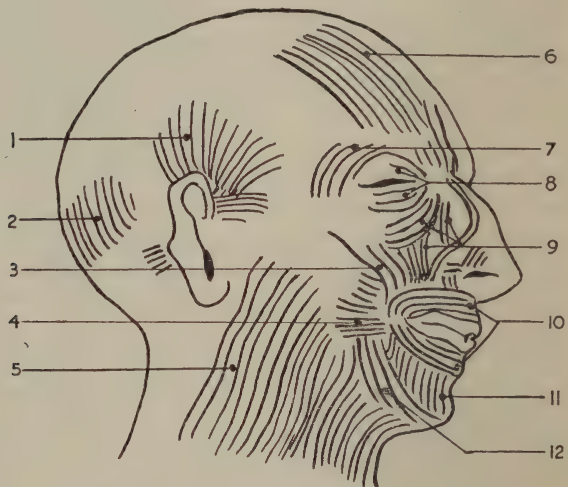

FIG. 11. The facial muscles. 1. Auricularis. 2. Occipitalis. 3. Zygomaticus. 4. Risorius. 5. Platysma. 6. Frontalis. 7. Corrugator supercilii. 8. Orbicularis palpebrarum. 9. Levator labii superioris. 10. Orbicularis oris. 11. Levator menti. 12. Depressor anguli oris.

The mechanism of closure is obviously stronger than the mechanism of opening, which may often be a kind of release action, seen when the lower jaw drops in an expression of astonishment.

§ 8·5. The action of the articulatory mechanisms for individual speech sounds will be described in detail in Chapter V. The consonants are produced primarily by articulatory mechanisms, and certain so-called voiceless consonants are produced without the act of phonation. In

cases of œsophageal speech after excision of the larynx, the phonatory action may be performed by the orifice of the œsophagus, when air is swallowed into and expelled from the stomach. In certain, fortunately rare, cases of the excision of the tongue, the closure of the oropharynx may be produced at the region of the epiglottis between the stump of the tongue and the posterior pharynx wall. In standard English the nasopharynx is closed off for all speech-sounds except the nasal consonants [m, n, ŋ]. A tongue-pharynx closure has been observed as a substitute for the glottal stop. Borel-Maissony, **309.**

§ 8·6. The relative rapidity of movements of the various articulatory speech-organs has been studied. Stetson, **290,** p. 85. The sequence of rapidity from fastest to slowest is firstly the tongue-tip, then the jaw, then the back of the tongue, the lips, and finally the soft palate. The speeds vary from 5·2 to 9·6 per second. It is interesting to note the frequent recurrence of a speed of six to seven movements per second in varied forms of muscle action. Thus the average speed of the vibrato, the frequency of the repetition in the stutter and the average rapidity of clonic spasms in tetanus are all about six to seven per second. This important correlation will be dealt with later in Chapter V and Chapter IX. Singers are apparently capable of a great degree of control over the articulatory organs and especially the tongue. They are capable of shaping the upper surface of the tongue in a concave fashion, thus creating an oval cavity in the mouth between the palate and the tongue surface. Curry, **270.** The articulatory organs are prime factors in the action of playing the flute when the pitch of the note depends upon the tension of the lips and the position, diameter and shape of the lips aperture. Roos, **338.** Conversely the ventriloquist is required to achieve virtual immobility of the articulatory organs that are visible to the audience. Thus the absence of tongue, lip and jaw actions must be compensated for by contractions in the oropharynx between the epiglottis and the posterior pharynx wall.

Borel-Maissony, **309.** The labial consonants [p, b, m, f, v] are articulated by producing plosion between the tip of the tongue and the teeth and lips. Paget, **160,** p. 228. X-ray studies of the speech cavities for the ventriloquist show extraordinary contortions of the speech organs.

CHAPTER III

THE ACOUSTICS OF VOICE

§ 9·1. Consideration will here be given to the acoustical problems of the human voice, and in particular to the dynamical and mechanical action of the larynx. But in preparation for the discussion it is advisable to state certain definitions of terms in general use throughout this work. Certain of these definitions constitute limitations of the wider popular senses given to the terms. Firstly, it is advisable to draw a distinction between sound and noise. Sound may be defined as a vibratory movement of air molecules taking place at a more or less regular rate of vibration per second. Noise is defined as a vibratory motion of air molecules taking place without this regular rate of vibration per second. In sound the deviation of the rate from the mean value must be quite small as compared with the total value. Each complete vibratory movement, representing a complete set of the vibratory action performed by the sound source, is termed a cycle. This is designated by the symbol ∼. A tone is a musical sound. An air-borne sound wave is propagated by the alternate compression and rarefaction of the air molecules over a spherical wavefront travelling in the direction of propagation of the sound. The velocity of propagation of sound varies with the medium in which it is propagated. In air it is about 330 metres per second; in water about 1,500 metres per second; and in steel about 5,100 metres per second. The velocity increases with the density of the medium. The extensity in a given medium of one cycle of the sound wave is called the wavelength. The extensity in time of one cycle of the sound wave is called the period.

§ 9·21. Vibratory action, including sound and noise, may be simple or complex. The constituent parts of a complex action are called components. All vibratory action, including sound and noise, possesses five characteristics. These are, in order, frequency, intensity, period, phase and quality. In acoustics the frequency of a sound is the number of complete cycles occurring in one second. Pitch is the subjective auditory impression of frequency. Intonation is the pattern of successive frequency changes in the fundamental frequency of a given sample of progressive vocalization. Inflection is the direction of this frequency change, whether rising, falling or level. A musical scale is a series of tones arranged in descending or ascending sequence of pitch and linked by definite numerical relationships. A natural musical scale is one in which these relationships of pitch can be expressed by the ratios of whole small numbers. An even-tempered scale is one in which these relationships are all equal. The octave is the relationship between two pitches in the ratio of 2 : 1. The major diatonic scale has seven intervals to the octave. An interval is a difference of pitch between two notes on a scale. The chromatic scale has twelve intervals to the octave. The international, physical and acoustical scale has established the pitch referred to as middle C at a frequency of 256 cycles. The concert musical scale has the pitch of middle C at the frequency of 261 cycles.

§ 9·22. The intensity of an air-borne vibration refers to a physical quantity, which determines the rate of supply of vibrational energy per square centimetre of wavefront. This energy is proportional to the product of the amplitude squared and the frequency squared. In a sound wave the intensity is nearly inversely proportional to the square of the distance between the sound-source and the position of the receiver. This nearly square-law relationship is due to the spherical wavefront of the sound wave in air. The amplitude is the measure of the greatest deviation of any air molecule in the path of the sound wave from the mean value of any cycle of the wave. Hence for a given flow of

energy, a high-frequency vibration has much less amplitude than a low-frequency vibration. The loudness of an air vibration is a subjective impression formed by the hearer. It depends upon, firstly, the intensity of the vibration, secondly, the sensitivity of the ear for the particular frequency of the vibration, and thirdly, the characteristics of the medium in which it is propagated. The intensity of the vibration will depend on the mechanical action of the source; the sensitivity of the ear varies with the frequency; and the propagation of the wave will vary with frequency and intensity. In language, the loudness of a given speech-sound is the measure of the accent or stress of the sound. A scale of equal intervals of physical intensity is linear. A scale of equal intervals of loudness is not linear, but is nearly logarithmic (*vide* below, Chapter VII). Volume designates a psychological impression of sound by which high-frequency sounds appear larger than low-frequency sounds.

§ 9·23. As defined above, the period is the extensity in time of a single cycle of the progressive sound wave. It is hence the reciprocal in time of frequency. Duration is the extensity in time of a sequence of cycles of any prolonged vibratory action. The phase is the fraction of the whole period which has elapsed, measured from a fixed origin. It is usually indicated by the degrees of arc of a circle formed by the fraction, the whole period forming 360 degrees. In the relationships between two or more vibratory actions, if these two or more actions result in the same reaction at the same time on the air molecules, they are said to be in phase. If they tend to opposite results on the air molecules, they are said to be out of phase or in opposite phase. Tone quality is the subjective impression of the nature of the sound wave, depending upon the number of components and their relative intensities, frequencies, periods and phases. The fundamental component is that one having the lowest frequency. An harmonic is a component, the frequency of which bears an integral numerical relationship to the frequency of the fundamental. An overtone is a component, not always

harmonic, which has a frequency higher than that of the fundamental. In voice the fundamental component is always the frequency of vibration of the vocal cords.

§ 9·3. In the musical scale the more important intervals, with their frequency relationships, are the following :—

Unison. 1 : 1.	Fifth. 3 : 2.
Minor third. 6 : 5.	Major sixth. 8 : 5.
Major third. 5 : 4.	Minor sixth. 5 : 3.
Fourth. 4 : 3.	Octave. 2 : 1.

In a diatonic musical scale the frequency relationships of the intervals are the following :—

C	D	E	F	G	A	B	C
1	1·125	1·25	1·3	1·5	1·6	1·875	2

A chord is a combination of tones sounded together, whose frequencies are in the ratio of small numbers. A diad is a combination of two tones sounded together, whose frequencies are related as the ratio of small whole numbers. A tetrad is a chord of four tones. A majcr triad is a chord of three tones, whose frequencies are in the ratio of 4 : 5 : 6. Harmony is the auditory subjective agreement of tones produced simultaneously.

§ 9·4. Resonance is the co-ordination of synchronization of the free and the impressed vibrations in a body. Reverberation is the prolongation of reflected sound in an enclosed air space. The time of reverberation is the interval of time taken for a given sound to die away to one-millionth part of the original intensity. Diffraction of sound is the unequal diffusion and propagation of sounds of different frequencies. Sound filters are devices by which components of different frequencies in a complex sound may be unequally propagated. A high-pass filter is a device by which high-frequencies are propagated selectively. A low-pass filter is a device by which low-frequencies are passed selectively. A band-pass filter is one by which only a given band of frequencies may be propagated.

Vibratory Motion

§ 10·1. The whole study of acoustics is a study of vibratory action. A body has a definite property of stiffness, which is the opposition to displacement of the static or equilibrium position. When the body is displaced from the position of equilibrium and then released, the body tends to return to the equilibrium position. Provided the damping, or the resistance to motion, is small, the body overshoots the equilibrium position and thus begins an oscillatory motion, the frequency of which depends largely upon the mass and the stiffness of the body. When the displacement is small, as in the case of sound, the restoring force is proportional to the displacement. When the displacement is large, it reacts upon the period of vibration in an inverse logarithmic function,

$$T \propto \log_{10} I \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The simplest concept similar to the action of the larynx is that of the motion of a body attached to a compressible spring, the further end of which is fixed. The body is the vocal cord edge ; the spring is the stiffness of the muscle tissue ; and the fixed end is the thyroid cartilage. If the strength of the spring is such that the force tending to restore the mass to equilibrium position is equal to s times the displacement, the function s is called the stiffness constant of the system. The equation of motion of such a system is the following :—

$$m\ddot{\xi} + s\xi = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

(ξ represents the displacement at any moment from the equilibrium position.)

If in addition the mass experiences a resistance $r\dot{\xi}$, proportional to the velocity ξ, equation (2) becomes

$$m\ddot{\xi} + r\dot{\xi} + s\xi = 0. \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In complete absence of the resistance r, equation (2) becomes :—

$$\xi = A \sin (nt + \theta) ; \dot{\xi} = nA \cos (nt + \theta) \quad . \quad (4)$$

This represents the simple harmonic type of undying oscillation : the sine curve. In the case of small resistance the equation gives an expression indicating that the amplitude of the oscillatory motion decreases logarithmically. When the resistance is large, the motion may be a simple return to the equilibrium position or the sum of two decaying motions containing no periodic components. This latter state is called dead-beat, or fully damped.

§ 10·2. The magnitudes of the air displacements in a sound wave are quite small. Thus, for example, the diaphragm of a loudspeaker may not move more than 1 or 2 mm. in propagating an intense sound wave. In simple harmonic motion the period of the oscillation is given by the equation :—

$$T = 2\pi/n \quad . \quad T = 2\pi\sqrt{m/s} \quad . \quad . \quad . \quad . \quad (5)$$

(where $n^2 = s/m$, m is the mass, s is the stiffness constant). Hence it is seen that the period increases with the mass and decreases with the stiffness. While the mass for any given body is constant, the major factor determining the period is the stiffness, and this is largely dependent upon the composition of the body. The material most commonly used in the imitation of the vocal cord action is rubber in the form either of sponge or of small bags, containing air at different pressures. It is interesting to note that, when rubber is entirely confined, it is nearly incompressible. Hence any deflection and displacement is taken up by changes in shape rather than in volume.

The Action of the Larynx

§ 11·1. In considering the possible action or actions of the larynx as a vibrating system, it is important to bear in mind the virtual impossibility of determining on the living person the precise character of the larynx sound. The sound wave

as recorded at the lips or in external air represents the reactions of the speech cavities upon the larynx sound. It is possible here only to put forward the probable explanations of the vibratory action of the larynx, based upon the evidence collected from various sources. The vocal cords perform a complex vibratory action in producing sound. In the normal (as opposed to the falsetto) voice, the vocal cords come into direct contact at the beginning and the end of each vibration cycle. The anatomical composition of the vocal cord consists of the surrounding nearly rigid structure of the thyroid cartilage, the tensed tissue of the thyroarytenoid muscle, and the overlying layers of epithelial tissue. The cartilage must constitute a rigid boundary to the cord, though it is considered that a certain degree of compression of the thyroid cartilage may take place by the contraction of the external sphincter muscles. Némai, **322.** The vibratory motion of the cord thus consists of the compression of the muscle tissue and the displacement of this tissue horizontally and upwards into the free space of the ventricle. Accordingly, the lateral motion of any given point on the edge of the cord must consist of a roughly elliptical path, being the resultant of a larger horizontal movement and a much smaller vertical displacement. By reason of the variability of this motion, the resultant vibratory waveform must contain a complex structure of a fundamental and an extended range of harmonics, the amplitudes of which probably diminish exponentially. Inharmonic components in the waveform of voice are most probably due to sporadic vibrations of limited parts of the larynx, in particular, to vibrations of the mucous globules coating the cords. The average maximal displacement horizontally is 4 mm.; the estimated vertical displacement in the normal case is about 0·2 mm. Husson and Tarneaud, **291**, p. 982. The lower surface of the cord is inclined out into the lumen of the trachea at an angle of about 45 degrees, and the pressure of the air stream from the lungs is at right-angles to this surface. Hence a slight vertical component in the displacement is

produced. In cases of abnormal voice, as in the paresis of the adductor muscles, the vocal cords perform a large horizontal motion. Tarneaud, 247, p. 37.

§ 11·2. By reason of the increasing muscular tension, both by action of the internal muscles tensing the cords, and the action of the external muscles pulling on the attachments of the cords, the stiffness constant of the cords increases. Hence the natural period of vibration will decrease and the frequency will increase. In these circumstances, the cord behaves as if it were a body of changing composition. This change in stiffness may increase to a maximal value for s, which is reached at the stage of maximal internal tension of the thyroarytenoid muscles. From this point onwards the production of higher frequencies can be effected only by alteration in the mode of vibration of the cords. The stiffness of the cords is now increased by a separational pull on the end attachments of the cords, anteriorly at the thyroid cartilage, and posteriorly at the arytenoid vocal process. The internal muscles—the thyroarytenoids—are less tense, and the external muscles, especially the cricothyroids, are more tensed. The cords touch only on 1 to 2 mm. of their depth, and the vertical displacement increases to 1 or 2 mm. This latter is due to the raising of the cord edges. The vibratory action still consists of the compression and swelling upwards of the tissue into the ventricle.

§ 11·3. A third action of the larynx, which is described fully below, is called the falsetto voice, when it occurs in man, and the whistle register, when it occurs in woman. It carries on from the upper limit of the normal voice in both cases. The vocal cords do not vibrate in the manner described previously. The cords are closed together for a brief part of the cycle and the separational action is even more reduced as to amount to only some 2 mm., while the upward displacement is increased to 2 mm. In this case the motion is still that of the separational type. But in other cases of this voice, and especially in the whistle voice, the cords may have an oval gap between them, which usually comes towards the anterior part

and the middle, and amounts to a maximal orifice of about 1 to 2 mm. This occurs apparently at the point of least rigidity of the cord edge. Husson and Tarneaud, **291**, p. 966. In this case, the sound is produced as an edge-tone, stimulated by vortex formations in the air passing through the orifice. The frequency is naturally high and depends upon the diameter of the orifice. The edges of the cords vibrate in a limited way, but it is not probably the whole of the cord which is displaced as in the normal.

§ 11·4. The larynx is to be considered as a maintained vibrating system, having a large resistance or damping factor, and maintained in vibration by the pressure of the subglottic air. It also forms the lower part of a tightly coupled system of cavity resonators by reason of which the cavity resonances react upon the source of sound. The subglottic air undergoes pressure changes at the beginning and the end of each vibration cycle. There is a wave of rarefaction of the air molecules propagated in the trachea at each opening of the glottal aperture, and a wave of compression at each closing. Trendelenburg, **380–2**. The modifications in the vocal cord composition in the normal voice for higher and higher frequencies of vibration consist of the increased tension, and hence rigidity of the thyroarytenoid muscle and the separational pull on the end-supports of the cord. It is improbable that the thyroarytenoid muscle can contract and expand under nervous control at the high frequencies involved in voice. This is especially true of frequencies above 1,000 cycles at which the upper limit of action currents in nerves is reached. The nerve action partakes rather of the assurance of a given tension in the muscle, which, under given conditions of the firmness of closure together of the cords and the area of glottal surface in contact, will assure a given natural frequency of vibration. Increases in the air pressure, above the minimal value necessary to initiate vibration at a given frequency, determine the amplitude of the vibration, and hence the intensity of the sound produced. The relationship between amplitude of vibration and the intensity

of the sound follows roughly the square-law principle.

§ 11·5. It is interesting at this juncture to consider the mechanical action of the models simulating the vocal cord vibration. The most successful of these were made by the physiologist, Ewald, **278**. The vocal cords were represented by wedge-shaped projections into the bore of the tube, which represented the trachea, and were supported by internal compressible springs. Others consisted of rubber air sacs which could be inflated to different pressures. Those having an inclined lower surface and a horizontal upper surface could be excited by air only from below. Other types could be operated by air from above and below. In these models the frequency of vibration is independent of the air pressure for normal values, and dependent upon the elasticity of the rubber wedges. However, if the air pressure was increased greatly, the frequency dropped, because the frequency was not entirely independent of the amplitude of vibration. Husson and Tarneaud, **291**, p. 989. The wave-form of the sound produced by models of this type is generally one having a large initial amplitude of displacement and having many component tones. The acoustic effect is that of the vowel [a] on a harsh quality. A simpler experiment, which has been performed successively by Harless (1853) Ewald (1898), Negus (1929), and Müller (1938), consists of using two strips of frog muscle as artificial cords stretched over the mouth of a tube leading from an air bellows. The rigidity of the muscle is varied by means of electrical stimulation of the muscle fibres. The results of this experiment are somewhat similar to those obtained with the *Polsterpfeifen.*

§ 11·61. In summarizing the position of the investigation of larynx action, reference must be made to an excellent account published recently. Husson, **295**, p. 19ff. The analysis of the present knowledge may be considered the following. The physiological energy, supplied by action of the respiratory and phonatory muscles, is dissipated in two main forms: firstly, the progressive sound wave in the

supralaryngeal cavities and the air pulses in the trachea; and secondly, the parasitic vibrations of the structures linked to the larynx. The laryngeal sound consists of a dominant fundamental with an extended range of overtones and possible frictional inharmonic components varying from cycle to cycle. Lewis, **304**, p. 91. It varies with the type of speech-sound or the singing, with the frequency of the fundamental and with the intensity. The sound wave in external air is dependent upon the reactions of the vocal cavities upon the laryngeal sound. The subglottic volume of the trachea and the bronchi constitute a resonator reinforcing the fundamental in decreasing effectiveness from about the lowest note of the voice up to about 256 cycles. The natural frequency of this subglottic space is always below the lowest note of the range. Trendelenburg, **381**, p. 45. The subglottic air is thus in forced resonance with the fundamental. The cavities of the oropharynx, mouth and nasopharynx may act in forced or natural resonance to increase the intensity of the fundamental and/or certain components by reducing the damping coefficient of these components. The cavity resonances do not supply energy, but only act to increase the flow of energy from the source in the larynx. The accessory nasal sinuses act, if at all, only to absorb energy from the larynx sound. A certain amount of energy is absorbed in the parasitic vibrations of the larynx structures, the skull and the thorax. It is wrong to postulate the sound wave being deflected to various parts of the vocal system by the obstacles of the epiglottis, tongue, etc. The wavelength of the sound is much too long to be affected by the relatively small area of these parts, such as the epiglottis. The progressive wave of air vibration at each cycle of the larynx vibration is propagated almost instantly through the whole volume of the vocal system, and there are only negligible phase differences in various parts of the system. The sensations due to sympathetic vibrations of various parts of the vocal system, such as the hard palate, skull, thorax, etc., are sources of the false concept

that the sound wave is directed selectively to those areas.

§ 11·62. The sound energy in outer air increases with the more 'open' vowels for which the normal mouth passage increases in width progressively in the sequence [i, e, ϵ, a, α]. It varies with the mode of vibration of the cords and the consonance or dissonance of the larynx sound and the cavity resonances. The close coupling between the larynx sound and the cavity resonances is shown by the occurrence of laryngeal disorders resulting from dissonance of the two actions. These disorders may often produce organic lesions of the cords. Tarneaud, **247**. A sharply resonant cavity may react upon the frequency of the larynx vibration. Weiss, D., **387**. It is probable, however, that the resonance characteristics of the vocal cavities are broad and cover a range of frequencies. Cotton, **268**. They may resonate more or less equally with several components in the larynx sound, and hence act as filters modifying the intensities of various components. The accurate analysis of the component tones of a speech sound shows rather a pattern of peaks of intensity of the components than a limited number of single frequencies of resonance.

§ 12·1. The energy relationships between the vibratory motion and the resultant sound intensity are difficult to determine for the larynx action. Models or larynxes excised from the body do not function exactly as does the living larynx. Apparently, the actual intensity of the sound produced constitutes only about 20 per cent. of the total energy produced at the larynx. Husson, **295**, p. 20. The rest of the energy is dissipated in parasitic vibrations and in the sound pulse in the trachea and bronchi. The equation of energy for a vibrating system performing simple harmonic motion is :

$$\frac{m\partial^2 x}{dt^2} + \frac{r\partial x}{dt} + sx = F \cos pt \quad . \quad . \quad . \quad . \quad (6)$$

where F cos pt is the external periodic force of maximum value F and frequency $p/2\pi$.

r is the resistance per unit velocity.
s is the restoring force per unit displacement.
m is the mass.

The total energy of the mass performing simple harmonic motion is given by the equation :

$$\text{I} = 2m\pi^2\alpha^2n^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where α is the amplitude, and n is the frequency.

Hence, if p is the root-mean-square value of the pressure variation in the air in dynes per square centimetre, and c is the velocity of sound in centimetres per second, and ρ is the density of air in grams per square centimetre, then :

$$\text{I} = p^2/c\rho \text{ ergs per second per square centimetre} \quad . \quad . \quad (8)$$

(10 ergs per second equal 1 microwatt). Average values of the intensity for a speaker in a small auditorium vary between 10 and 50 microwatts. The range may be very wide from a maximum of about 1,000 microwatts to a minimum of 0·001 microwatts. This is a range of 1,000,000 to 1 or 120 decibels. Fletcher, **40**, p. 67. The value of the RMS pressure variations in the air can be found by means of a condenser microphone, and the following estimates have been given. Fletcher, **279**, p. 97.

Voice.	Pressure (dynes per sq. cm.)			Pitch range.
	pp.	mf.	ff.	
Bass . . .	13	18	31	80 to 256 cycles
Tenor . . .	14	21	34	140 to 512 ,,
Soprano . . .	14	20	24	384 to 1,024 ,,

In the distribution of energy over the frequency range in speech, the maximum is contained in the region 150 to 250 cycles, and over 80 per cent. is contained in the region 50 to 750 cycles.

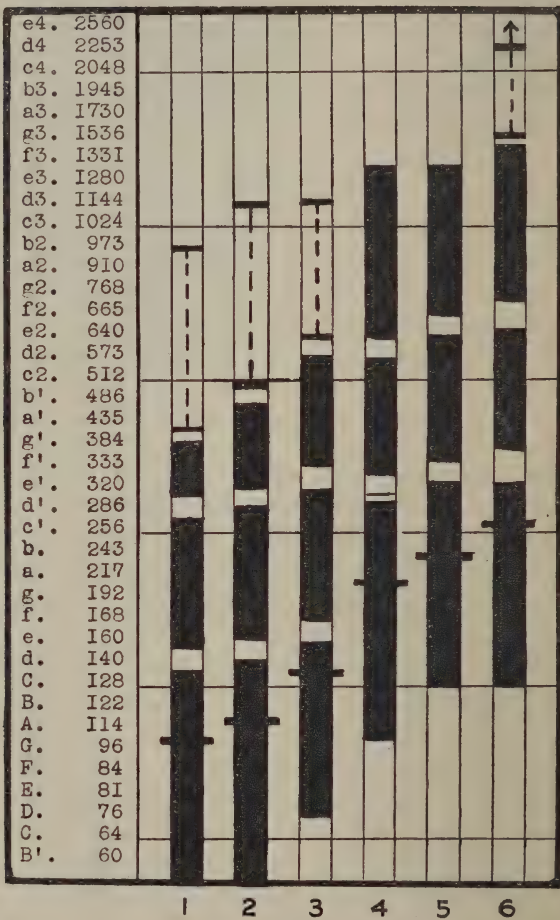

FIG. 12. The ranges of the human voice (Nadoleczny). 1. Bass. 2. Baritone. 3. Tenor. 4. Contralto. 5. Mezzo-soprano. 6. Soprano. The horizontal black lines indicate the average pitch of the speaking voice for each type. The gaps in the ranges indicate the approximate positions of the transitions. The dotted areas are the falsetto voice. The area marked by arrows indicates the whistle range in children.

Resonance

§ 13·1. The action of resonance as a factor in voice has been subject to a great deal of confusion and misunderstanding. In musical writing the term is often misinterpreted and misused as a cloak for a lack of definite explanation. Drew, **274**, p. 125. The term has already been defined, and it remains here to consider some of the forms that constitute the action of resonance in voice. In the process of establishing a state of resonance between two or more vibrating systems, the closer the synchronism between the frequencies of the various systems, the greater the degree of coupling and the greater the amplitude of the resulting resonant vibratory motion. The action of the resonator, which is not in itself a source of vibratory action, is to reduce the resistance of the medium in which the vibration is propagated. Two main types of such resonators are in common use for this purpose. These are firstly, the selective resonator sharply tuned to a single frequency, and hence capable of greatly reinforcing the effective loudness of a sound of that frequency. This is exemplified by the organ pipe, which is tuned closely to the frequency of the vibrating reed. In practical construction the process is reversed and the reed is often tuned to the pipe. The second type is the non-selective resonator covering a wide frequency range and acting to increase the effective area of the sound-radiating mechanism. This is exemplified by the trumpet or horn of a loudspeaker, which possesses a nearly equal response for all frequencies produced by the source and functions by replacing a small source by a large nearly plane source, working at the same rate. The air surface at the aperture of the horn constitutes the new sound source. The introduction of the resonator near the source provides a means by which the pressure variation Δp can produce a large particle velocity ξ with which it is in phase. The tuned resonator decreases the radiation resistance and neutralizes the inertia reactance of the source.

§ 13·2. The resonance properties of cylindrical pipes and spherical cavities have been determined experimentally and mathematically. But in the case of the vocal cavities the outlines are irregular and highly variable from time to time and from individual to individual. Furthermore, the relative rigidity, density and surface smoothness of the cavity walls vary greatly from one part to another of the system, and play a part in the determination of the natural resonance frequencies. In the larynx and pharynx the walls are mainly epithelial tissue over muscle and cartilage, while in the nasopharynx the walls are smooth and firm, except when the cavity is filled with secretions. The tension of the muscles lining the pharynx will vary the rigidity of the walls. In these cases the only satisfactory method of considering the resonance actions of the vocal cavities is to make use of the analogies between acoustical and electrical phenomena in connection with resonance. Stewart, **11**, p. 161. In this manner a short column of air is regarded primarily as a lumped mass and an enclosed volume is considered as a capacity.

§ 13·3. In speech the two main types of sound resonators may be exemplified. The selective resonator is to be found in the speech cavity shapes for the vowels [u, i]. For these the waveforms show a limited number, usually three, of areas of strong component tones, indicating the result of selective filtration of the larynx sound through a resonator system tuned to these respective frequency regions. In this case, it is by no means certain that the intensity of sound in outer air is necessarily greater than that at the larynx. The type of the non-selective resonator is to be found in the cavity shapes for the vowel [ɑ], for which the waveform shows a wide band of frequencies covering many components of the larynx sound, and indicating the absence of great modification of the larynx sound, but the presence of a certain increase in the intensity. The increase in intensity is probably dependent upon the ratio of the cross-sectional area of the larynx aditus and that of the lip aperture. An examination of the X-ray outlines for vowels shows that

those typical for the vowels [u, i] are most similar to that of a series of connected Helmholtz resonators, while that for the vowel [α] is most similar to that of a trumpet or horn. Russell, **242**, p. 102.

§ 13·4. In voice the coupling between the source in the larynx and the resonators of the cavities is very tight and the resonators may react upon the source. The effect is to exert upon unit area of the source a pressure equal and opposite to that which the source exerts upon the unit area of the resonating medium. In singing this may result in an excessive amplitude of vibration of the cords producing only a small intensity of voice. Husson, **292**, p. 1,536. As the fundamental frequency of the voice is raised higher and higher, obvious accommodations must take place in the system of coupled resonators if the relatively sharp tuning to the components of the larynx sound is to be maintained. Theoretically the maximum of resonance takes place in voice when the lowest natural resonating frequency of the cavities is the same as the fundamental of the larynx. This is especially necessary in singing, when the vocal cavities are used mainly as tuned resonators reinforcing the intensity of primarily the fundamental and the first and second harmonics. In the trained voice this accommodation should be accomplished smoothly. In the untrained voice these necessary accommodations come as punctuations of the steady rise through the frequency range of the singer, and these periods are called the transitions. They occur at the stages in the scale when the natural resonances of the cavities no longer synchronize with the fundamental but tend to fall on the next higher harmonic, and so cause a changed sensation due to the altered reaction upon the larynx sound. The quality change in the voice is perceptible when the two proximate harmonics reinforced successively by the same resonator are sufficiently variant in intensity so that there ensues a large modification of the energy transmission from the larynx to the pharynx cavity. This modification of the energy relationship reacts upon the larynx mode of vibration to produce a

sensation of distress which may result in conditioned reflexes which are likely to produce functional disorders. Husson and Tarneaud, **247**, p. 107.

§ 13·5. The precise pitches at which these transitions occur vary according as the singer is singing up or down the scale. The transition will occur higher on ascending the scale and lower on descending the scale, in accordance with the tendency to delay the transition. They vary also in connection with the tessitura of the voice; they are a semitone lower in the bass than in the baritone. They are a semitone lower on small intensities and nasality than on great intensities and non-nasal sounds. It is difficult to decide the respective functions of the pharynx and mouth cavities as resonators in singing. It is claimed that the principal resonator for the chest voice (that is for pitches up to about 587 cycles) is the pharynx and for the upper range the mouth cavity. Husson, **294**, p. 183. In general the study of the waveform of voiced sounds in singing shows that on low fundamentals up to about 500 cycles the cavity resonances tend to synchronize with the harmonics of the larynx sounds, while on high frequencies above 500 cycles the cavities resonate with the fundamental. For this reason the high-pitched tones of the soprano voice, from about 800 to above 1,024 cycles, consist mainly of the dominant fundamental and the first and second harmonics. The audible quality of these tones is 'clear and brilliant,' and the characteristic vowel quality is weakened or even absent. In other studies of this kind, experiments have been conducted with a resonator of known natural frequency coupled to the mouth so as to estimate the frequencies of resonance of the vocal cavities by means of the coupling effect of the additional resonator. Weiss, D., **390**. This effect may go so far as to alter the pitch of the transitions between the registers.

Analysis

§ 14·1. Analyses of the waveforms for all kinds of vocal sounds have been carried out by many investigators. The

more recent studies are performed either upon photographic records obtained with an oscillograph, or upon the original microphonic transmission of the sound. Thienhaus, **370**; Gemelli, **281–4**; Barczinski, **256**. Analysis of the photographic records may be done on the basis of Fourier's theorem, which stated that any function, which within a given interval is single-valued, finite and continuous, may be represented by a series of sinusoidal functions, whose frequencies are in harmonic relationship. The direct methods of analysis of the original sound wave are performed electrically by various means and do not always depend upon the harmonic principle. Vierling, **383–5**. The early theories of the composition of voice tended to form two distinct groups. These were firstly, the supposition that the sound consisted of the harmonics and fundamental of the larynx tone, selectively reinforced by the cavity resonances in a pattern which varied for each vocal sound. (Helmholtz.) The second was the theory that the larynx sound excited the natural resonant frequencies of the cavities, which need not be harmonics of the larynx sound. (Hermann.) Actually, the probable position is a combination of both supposedly antagonistic theories. Vocal sound is the product of a larynx sound having a fundamental and harmonics, which are reinforced or suppressed selectively by the vocal cavities, which may contribute inharmonic components by the vibration of specific parts of the vocal organs. These inharmonics are the product of friction of the air passing constricted zones of the passage. The cavity inharmonic resonances are the product of negative pressure fluctuations and eddy tones. Berger, **260**, p. 164.

§ 14·2. Analyses of the waveforms for vowels are more or less in agreement. The harmonic spectra, that is, the patterns of the intensities of the harmonics of the larynx sound, show for each vowel a series of distinctive frequency regions in which the larynx harmonics are represented in considerable intensity. These may be called formants or transmission-regions. These transmission-regions are distinctive for each

vowel. The dynamic picture is that of a set of filters selectively transmitting those larynx harmonics that fall in these frequency regions. It is claimed that there is a relationship between the positions on the frequency scale of the transmission-regions for each vowel. Kucharski, **302.** On the basis of the harmonic spectra and the relationships of the transmission-regions vowels may be separated into three groups. The type-vowels for each group are as follows: for group 1, the vowel [u]; for group 2, the vowel [ɑ]; for group 3, the vowel [i]. Curry, **14**, p. 114; Gemelli, **284**, p. 134ff. The first group, with the vowel [u] as the type, is characterized by a simple spectrum of a strong transmission-region covering the first and second harmonics and a much weaker region at about 2,200 to 2,500 cycles. Other vowels of this group are [ʊ, ɔ], for which the spectra change in that order towards the type of the second group. In this change the strong transmission-region rises progressively in frequency and the weak region becomes more prominent. The dynamic picture for the type vowel [u] is that of a filter system, which passes two main frequency bands. In the progressive change towards the second group the two bands widen and move closer together on the frequency range.

§ 14·3. In the type vowel [ɑ] for the second group, the spectrum shows an extended range of harmonics (some 7 to 10) which contain most of the energy and are so related in amplitude and phase that the resulting waveform has a large initial amplitude which is soon greatly damped down. Gemelli, **284.** The vowels [ɒ ɐ] represent a change in the direction of group 1, and are characterized by an increasing prominence of the transmission-regions in the high and the low frequencies. The vowels [a, æ] represent a change in the direction of the third group. The dynamic picture for the type vowel [ɑ] is that of a filter system reinforcing the general intensity of the larynx sound, without exerting any considerable modification upon the harmonic composition. The vowel [a] in a harsh quality probably comes nearest to the original larynx sound.

§ 14·4. In the case of the third group, the extreme type vowel [i] shows an harmonic spectrum having again two main transmission-regions of about equal importance, one in the low frequencies covering the fundamental and the first and second harmonics, and the second in the high frequencies covering harmonics in the region of 2,500 to 3,500 cycles. The dynamic picture is again that of a selective filter system transmitting two bands of frequencies, which probably are partly stimulated in the larynx sound by selective modification of the vibratory action. Strong, **360**, p. 22. The vowels [e, ɪ, ε], represents a progressive change in the direction of group 2, while the vowels [y, ϕ, œ] represent the change to group 1.

§ 14·5. The effects of changes in the fundamental frequency of voice upon the harmonic spectra for vowels depend upon the type of the group. In group 1, the vowel becomes changed in quality as the fundamental rises above about 512 cycles. Up to this point the low transmission-region covers progressively the second, first harmonic and fundamental, but from this point onwards the low region becomes greatly weakened and coincides with the fundamental. Meanwhile the high region strengthens and produces a resultant change in quality. For the second group the change with increasing fundamental frequency is not very great. The main effect is a reduction in the number of the harmonics present in the spectra. For the third group the main effect is an accentuation of the upper transmission-region, while the lower region coincides with the fundamental. This makes the vowel quality very shrill and often unpleasant on the very high pitches of the singer's voice.

§ 14·6. The spectra for consonants vary greatly according to the type of speech sound. The voiceless fricative consonants [s, ʃ, f, θ] show a great deal of high-frequency structure over the range of 2,500 to 8,000 cycles or higher. The voiced fricatives [z, ʒ, v, ð, ɹ] show a similar pattern with the addition of the fundamental and the first few harmonics. The continuant consonants [l, w] show a spectrum of three main

transmission-regions covering respectively the second to fourth harmonics, the region 1,200 to 1,600 cycles, and the region 2,300 to 2,600 cycles. Nasal vowels show a strong accentuation of harmonics in the region 300 to 700 cycles. Nasal consonants show a similar region about the same position, with another at 1,000 cycles, and the third at about 2,200 to 2,600 cycles. Naturally these regions are only approximate and will vary with the precise quality of the speech sound, so that it is possible to indicate only peaks of distinctiveness between the various types. The stop consonants are characterized rather by the temporal pattern of implosion, holding and explosion, with differences in the strength of the explosion.

§ 14·7. The harmonic spectra for sung vowels and consonants are characterized by the great simplification of the structure, especially in the high-frequency components. Any inharmonics present in speech sounds are greatly reduced or lost in the sung equivalents. On high-voice frequencies the structure for vowels is often simplified to a fundamental and the first and second harmonics. This is presumably the result of the artistic requirement of purity of voice quality and increased intensity of the fundamental.

CHAPTER IV

THE PHYSIOLOGY OF PHONATION

§ 15·1. In the study of phonation it is important to observe not merely the mechanism by which speech sounds are produced but also the nature of the speech sounds themselves. It is a legitimate criticism of much of the investigation of speech that the speakers who are investigated are not automatically typical of human beings in general except in very broad outlines. But it is equally legitimate to criticize investigations which confuse the general study with the particular details. By reason of the complexity of the study and the difficulty of investigation, objection may be made to all the important means of studying human speech on varied grounds of faulty apparatus, insufficient number of subjects, unusual psychological influences of the methods, interference with the normal manner of speaking, and so on. This should not prevent the investigator from proposing certain tenets and theories which naturally are subject to alteration after further study, but which are as valid as many propositions in psychology and allied sciences of human life.

§ 15·2. While it is possible to distinguish an individual by his speech from the general body of people in a speech community, it is yet also possible to determine vaguely certain points of uniformity in the speech of that community. It is possible further to distinguish as common units of all human speech four important characteristics of sound mentioned in Chapter III. These characteristics—pitch, quality, intensity and duration—play varying parts in the formation of the individuality of a single speaker, a speech community, a language, or a group-language. Accordingly, in the study of

the physiology of phonation these four factors may be discussed as the basis and foundation of human speech while the varied *rôles* played by these factors constitute the particular details of speech which are more complex and difficult to study. Of these factors pitch, intensity and duration are relatively easier to describe while quality assuredly has the greater variability.

§ 15·3. In phonation the control exerted upon the initiation and maintenance of the mechanism is twofold. It is firstly proprioceptive and evoked by internal neural sensations resulting from the muscular actions and the forces set up. Secondly it is extero-ceptive and consists of the sound percepts formed by the speaker as well as the visible reaction of the audience. The speaker's perception of his own phonation may be formed of both the audible sound wave in air and also the vibrations transmitted by bone-conduction through the skull. Accordingly, the normal individual is capable of exercising a fine degree of control over the factors which make up the sounds of speech. The extero-ceptive control of phonation by hearing is demonstrated when tests are made with congenitally deaf children who have never heard speech. Such children may be taught to imitate the movements of speech both in phonation and articulation, but it will be found that the weaknesses of their speech are essentially due to the lack of the auditory extero-ceptive control. For example, a child may articulate quite well but fail to produce the expiratory explosion at the end of the consonant. This is often partly due to a disco-ordination of respiration, thereby failing to produce the necessary air pressure behind the point of closure, but also it is due partly to the fact that the child does not hear the explosive hiss when the sound is pronounced. Yet the sibilants may be pronounced by the child quite well because the hissing vibration of these sounds can be perceived by the proprioceptive, kinæsthetic control. The monotone of voice is a characteristic factor associated with congenital deafness in children because the control of pitch change in the voice is largely the extero-ceptive,

auditory percept. Significantly, too, this monotone can occur also in cases of spasticity when the hearing is normal. Then it is associated with gross articulatory disorder and is probably the result of a general inattention to the extero-ceptive control. However, those who become deaf after speech has been learnt can apparently develop the proprio-ceptive kinæsthetic control to a high degree, since they must rely exceedingly upon this control of their speech. They also take note to an extent that is not often realized of the extero-ceptive signs of the reactions of the audience. Psycho-analysts often notice that their patients are very sensitive to changes in their surroundings and in particular to the reactions of the analyst. The deaf often develop a similar attention to those accessory behaviourisms and signs that the normal person overlooks.

Duration of Phonation

§ 16·1. The duration of phonation is controlled by the actions of beginning and terminating laryngeal muscular action. In voluntary overt speech the actions of beginning and terminating speech are under conscious control and consist of the beginning and termination of laryngeal muscle action for phonation. Naturally, speech may begin or terminate with a voiceless sound, and in this case the laryngeal action may be only a narrowing of the glottis. But since this discussion is concerned with phonation only, it is possible here to disregard these cases of voiceless sounds. The duration of phonation may be controlled by the duration of the expiratory stroke, and this period is called a ‘ breath group.’ Study of the respiratory action for speech shows that the muscle action for expiration begins shortly before the glottis closes for phonation. Three forms of co-ordination of respiratory and phonatory action may occur. The glottis may close before the expiration begins. In this case there may be a slight moment of inspiratory speech followed by expiratory phonation often of an abnormal type. Secondly, the glottis may close simultaneously with the beginning of

expiration. In this case the phonation may begin with a glottal stop or a brief period of overloud phonation which produces an unpleasant effect. This may especially occur in the attack in singing when the singer bursts into song with a disagreeable initial effort. Thirdly, the glottis closes after the beginning of expiration, and this produces the average, normal type of phonation, or, if the lag is greater than about 1/100th second, an aspirated type of initiation. There appear to be few disruptions of the manner of terminating phonation. Since glottal opening and inspiration are co-ordinated, the termination of phonation takes the form of the relaxation of the sphincteric closure of the glottis. Expiration need not terminate also with the end of phonation, but in overt speech the phrasing is generally arranged to provide suitable pauses for inspiration.

§ 16·2. The action of beginning phonation must involve the normal mechanism of closing the glottis and so the adductor and constrictor muscles. This involves the adduction of the vocal cords, so that the edges touch in the midline of the larynx, with often a narrowing of the larynx lumen and a raising of the cartilages. In this action the arytenoids are swung backwards and approximated so that the cords are brought together and meet. The horizontal part of the interarytenoid muscle approximates the cartilages while the oblique, strap-like fibres act to swivel the arytenoids round. At the same time the cricoarytenoid lateralis muscle aids in approximating the arytenoids and swivelling them round. The constrictors of the pharynx contract in sympathy with this general sphincteric action of the larynx. The cricopharyngeus muscle holds the cricoid in place, bracing it back like an attachment to the vertebral column, while the cricothyroid and the sternothyroid act to swivel the thyroid on the cricoid so that the anterior notch of the thyroid moves downward and a little forward. In antagonism to the movement of the thyroid the thyroarytenoid tenses the vocal cord, so exerting a forward pull on the arytenoid cartilage. This is balanced by the backward pull of the posterior cricoarytenoid,

which is tensed and so acts as antagonist to the cricothyroid. Some forward motion of the thyroid is effected by pull of the horizontal part of the cricothyroid. The abductor action is largely a relaxatory release of tension in the antagonists to the posterior cricoarytenoid, which is thus able to swing open the arytenoids and separate them. Certain variations may occur in the closing action. The arytenoids may not come into complete adduction so that there is a triangular gap between the edges of the vocal processes. This is often a form of paresis of the interarytenoid muscle or may be due to some variability of the surfaces of the cartilages. Moreover, the contraction of the pharynx may be reinforced to the point of considerable narrowing of the larynx and pharynx and the approximating of the ventricular bands. In that case phonation begins with a glottal stop produced at the ventricular bands. This is a common feature in German where most strongly accented initial vowels begin with glottal stops. In certain English dialects, especially Cockney, the glottal stop occurs medially instead of a voiceless consonant, such as [t]. Curiously enough, a stop consonant by closure between the root of the tongue and the pharynx wall may be substituted for the true glottal stop. Borel-Maissony, **308**. In cases of double voice, when the subject produces a voice having two fundamental pitches separated by a musical interval of a third, the ventricular bands are approximated and produce the lower pitch and the true vocal cords the higher pitch. Paget, **160**, p. 34. The ventricular bands are also approximated in sneezing and in coughing when a strong expiratory spasm is used to remove mucus or foreign bodies from the air passage. Negus, **238**, p. 265.

§ 16·3. Control of the duration of phonation must depend upon two main factors. In overt speech the control is mainly the auditory percept of speech formed by the ear of the speaker. The initiation of the muscular activity in phonation is then a conscious desire for oral self-expression. But in cases of mental recitation, or thought processes unaccompanied by overt speech, there are definite laryngeal

movements accompanying the mental processes. These sympathetic actions may extend to movements of the articulatory organs and the individual may be observed articulating speech without producing any sound. In this case the control over phonation and articulation must be the kinæsthetic sensations resulting from action of the speech muscles. These kinæsthetic sensations must give only a gross control of speech movements in the case of silent speech, and so those speech sounds producing the strongest and most distinctive kinæsthetic sensations, in particular the stop consonants, are best articulated in silent speech.

The Diverse Factors

§ 17·1. In the study of pitch, intensity and quality factors in phonation it is difficult to isolate any of these factors from association with the rest. Experiments can be made in which one factor is varied while the others are kept as nearly as possible invariable. Thus it is possible to vary pitch while keeping intensity and quality relatively constant. But it must be recognized that phonation under normal conditions is a resultant of all three factors. Except in very specialized circumstances the waveform of a speech sound is complex and contains many harmonics. The fundamental component determines the factor of pitch for the speech sound. This fundamental is produced and its frequency determined by the periodic vibration of the vocal cords. Over the pitch range for speech for either sex the mode of vibration of the vocal cords is relatively constant, but in singing the pitch range is greatly extended and the mode of vibration of the larynx changes for the higher and higher pitches. The pitch range in speech comes in the so-called ‘ chest ’ register, or the lower range of the singing voice of an individual, and extends over about 80 to 160 cycles for man and about 220 to 300 cycles for woman. In the case of a soprano voice the pitch range of her compass may extend from 200 to 1,024 cycles. The mechanism of the larynx is unable to cover this wide range on the same mode of vibration throughout and so the singer is

forced to use different actions of the larynx for the different parts of his compass. The small larynx of the baby is capable of producing a high pitch. The baby's cry is pitched at about 435 cycles, but the cry often becomes a high-pitched sound rising to 3,072 cycles. Normally the vocal range is small in childhood, being about 3 tones by two years and 1 octave by six years. At the onset of puberty the average voice has a range of $1\frac{1}{2}$ octaves. Seth and Guthrie, **172**, p. 197. In the adult the major distinction is between the normal and the falsetto voices. Within the limits of the normal voice certain detailed distinctions may be observed. In the female voice the falsetto is usually represented by the 'whistle' register, when it is present.

§ 17·2. Pitch change in the lower range of the normal voice, including the speaking range and the lowest tones of the singing voice, is produced mainly by action of the thyroarytenoid muscle. Since the laryngeal muscles have been classified into the intrinsic and extrinsic muscles there is a mistaken tendency to regard the action of these two muscle groups as forming two separate mechanisms. From general study it appears that the vibrating vocal cord behaves as a body of variable composition, maintained in the given, closed position by a force of varying strength depending upon the elasticity and tension of the thyroarytenoid muscle. The muscle has a resistance to movement depending upon the stiffness or elasticity of the vocal cord, and this resistance is high so that the restoring force is great. The material of the vocal cord is relatively incompressible by the force exerted by the air pressure from below, and so the vibratory action takes the form of a change in shape rather than in volume. In the action of displacement of the vocal cord during one cycle of vibration the plan of the motion of a given point on the surface of the cord is an elongated ellipsoid, and the change in shape of the cord is effected partly by compression of the cord and partly by displacement up into the ventricle. The horizontal separation of the edges of the cords in the open phase of the vibratory cycles may amount to as much as 4 mm.

Tarneaud, **247**, p. 21. In the normal voice the upward component of the motion is very small—at most $\frac{1}{2}$ mm.—but in abnormal conditions the upward motion may increase, or during inspiratory phonation the motion may be downward rather than upward, so that the vocal cords appear to be drawn down into the trachea. This mode of action is the result of a vocal disorder. The displacing force is supplied by the air pressure from the lungs and the restoring force by the tension of the thyroarytenoid muscle, the cross-section area of the vocal cord, the surface area of the cord opposed to the air stream and the general change in elasticity of the tissue of the cord.

§ 17·31. **The Low Pitch Range.** In the low range of the voice the laryngeal action is as follows. The vocal cords are approximated and tensed lengthwise as well as internally. The elongation of the cords is about 3 mm. The adduction involves action of the interarytenoid, the lateral cricoarytenoid, and the thyroarytenoid muscles. The cricoarytenoid posticus muscle braces back the arytenoid cartilage thereby fixing the posterior attachment of the cord while the cricothyroid and sternothyroid muscles hold fixed the thyroid and the anterior attachment. By the tilting down of the anterior body of the thyroid the level of the cords is lowered slightly in the neck so that while in the open, rest position they are tilted slightly upwards towards the anterior attachment, in phonation they assume a position some 3 mm. lower and are horizontal or even tilted slightly downwards towards the thyroid attachment.

§ 17·32. Meanwhile the thyroarytenoid contracts and accordingly swells, thereby increasing the cross-section area of the cord, increasing the rigidity and stiffness of the tissue and protruding the lower vertical face of the cord, so that a deeper vertical area of the cord comes into contact with the face of the opposed cord. This contact area increases up to about 5 mm. in depth. These changes in the consistency and form of the cord produce a faster natural period of displacement, and hence, for a given displacing force of air pressure,

would produce a higher natural frequency of vibration. This increasing contraction of the thyroarytenoid muscle with consequent raising of the pitch of phonation continues without any marked increased activity of the external laryngeal muscles up to the point of maximal contraction of the vocal cord tissues. After this stage, to produce higher pitches it is necessary that the external larynx muscles come into increased activity. By reason of the anatomy of the larynx the changes in the stiffness of the vocal cord may be effected by two means. Firstly, the contraction of the thyroarytenoid causes changes in the internal composition of the cord. But, secondly, the front and rear attachments of the cord may be pulled upon by contraction of the external laryngeal muscles in such a way as to exert a stretching force tending to antagonize the contractile force of the thyroarytenoid shortening the length of the cord. It must be noted that any stretching of the vocal cords amounts to only a few millimetres at most. The posterior attachment at the vocal process is held back fairly firmly by their attachments to the œsophageal wall, while the anterior attachment at the thyroid cartilage is held fixed and drawn forward by action of the horizontal cricothyroid and the sternothyroid muscles. By reason of the antagonism of the muscles the stretching action of the external muscles does not result in elongation but rather in increased stiffness of the cord and the tendency to thin out the ligamentous and membraneous edge of the cord producing the appearance of the so-called ‘ thin ’ cord, as observed in the upper range of the voice by laryngoscopic study by means of illumination from a source below the larynx level. In this way the edges of the cords show like translucent bands, which are even more translucent in the higher pitches. Evetts and Worthington, **222**, p. 20. The increase in the stiffness of the tissues of the vocal cords in this way gives a chance for a certain relaxation of the thyroarytenoid muscle. Hence the cross-section area of the cord reverts to the wedge-shaped form and the vertical area of contact between the cords in closure is decreased.

§ 17·4. There is a difference of opinion concerning the variety of modes of vibration of the vocal cords. The early theories, which likened the action of the cords to that of vibrating reeds, are invalidated by the observed facts. Instead of vibrating up and down, as these theories pre-

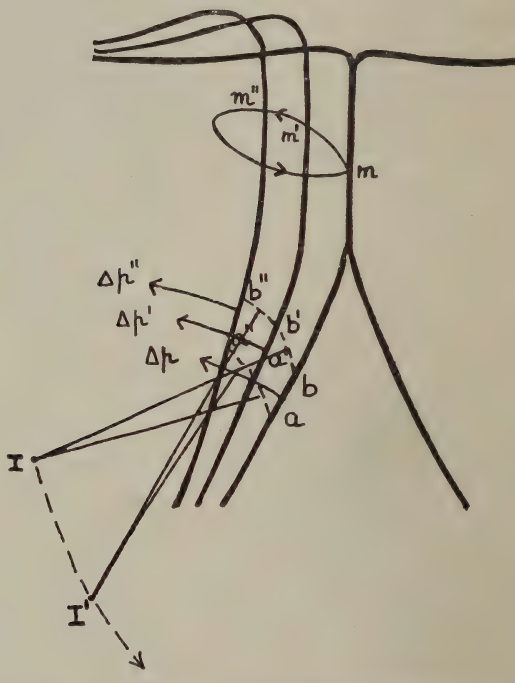

FIG. 13. A schematic plan of the vocal cord motion (Husson and Tarneaud). The effective motion is as if the cord had moved so that the point I had been displaced to the position I′.

supposed, the vocal cords move almost entirely in the horizontal plane. Liskovius, 233, 1814, first showed that one could touch the vocal cords at any point during vibration without altering the voice. The upward displacement of the edge of the cord during phonation is very small, amounting to about $\frac{1}{2}$ mm. Nor does the mechanism of the vocal cord

movement correspond in any way to that of a vibrating reed. Negus, following Lehfeldt, considered that there were two modes of vibration ; one being the normal voice for which the vocal cords were closed together and the air passed by separating the edges in a vibratory fashion ; while the second was the falsetto voice for which the cords did not close together but remained with a permanent, elliptical glottal opening, while the air pressure caused the free edges of the cords to vibrate. Negus, **238**. The most recent analysis, based upon stroboscopic studies, is put forward by Husson and Tarneaud, **291, 292–4**. They distinguish four modes of vibration, not all of which may be found in every person. These four modes of vibration may be discussed in the sequence of rising voice pitch. For the lowest pitches of the voice the singer attempts to make the vocal cords as lax as possible so that the natural frequency of vibration will be as low as possible. The superior cornuæ of the arytenoids are tipped forward to relax the vocal cords, and the singer may carry the whole action to an extreme in the effort known as ' low voice press.' In this effort to attain the lowest pitches the chin is drawn back into the neck in the attempt to relax the muscles linking the larynx, hyoid bone and mandible, to lower the larynx in the neck and to relax the vocal cord tension to the minimum necessary for the initiation of vibration. At this stage the pitch is very variable and the quality hoarse and deep-voiced while clear articulation is difficult. Over the low pitch range, which is called the chest register on an open quality, the period of closure of the cords is longer than the period of opening and closing. Thus O + R is less than C, where O is the period of opening, R is the period of recoil, and C is the period of closure. As the pitch rises and the thyroarytenoid contracts up to the maximum, period C increases up to two-thirds of the total vibratory cycle, while period O equals period R. The vertical area of contact increases and, just before the transition to the next superior register, the larynx contracts sphincterically while the ventricular bands move closer

together and the epiglottis is humped down over the larynx vestibule. In the untrained voice the transition to the next mode of vibration is abrupt and obvious, producing a jump in pitch of a fifth, while a distinct quality change occurs. In the yodel this action of alternation of vibratory modes, on the same pitch or on pitches separated by about a third, is used for a distinct effect. Husson and Tarneaud, **291.**

§ 17·5. **The 'Covered' Voice.** The next higher register after the transition, which according to Tarneaud occurs at about 652 cycles, involves a definite change in muscle action. This is particularly true of the untrained voice in which the transition produces an abrupt change from the 'open' to the 'covered' quality. In the trained voice the transition is gradual and imperceptible and the change in muscle action is neither abrupt nor violent. In the trained voice the change from the first to the second mode is performed gradually over the transition so that no obvious quality change occurs. In the normal, untrained voice the change is effected by a sudden increased activity of the external laryngeal muscles in assisting the thyroarytenoid which has reached its maximum power of contraction. The normal change of muscle action at this stage results in the gradual elevation of the larynx cartilages and the separational pull on the end attachments of the vocal cord. The hyoid bone, and with it the longitudinal cartilages, move upward and forward towards the lower jaw, while the level of the upper edge of the cords which normally tip downwards towards the thyroid becomes more horizontal or even tips upwards. The degree of upward displacement of the hyoid bone and larynx cartilages depends upon the extent of the pitch range and may amount to some 18 mm. in the case of the soprano voice. Curry, **269.** However, in cases of more limited pitch ranges the displacement may be less if the singer has learnt to rely more especially upon the first mode and does not extend the compass too far into the upper pitch range. This upward displacement of the larynx for higher pitches has been observed many times, and the degree of action varies with the type of voice, being

greatest in the untrained or youthful voice which is not kept to a restricted pitch compass. Any such elevation of the larynx is sometimes condemned as a faulty action, but it

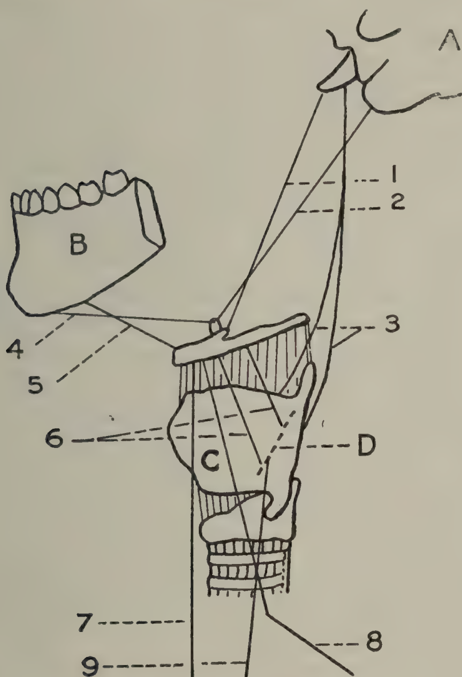

FIG. 14. The supra- and infra-laryngeal muscles. A. Styloid process. B. Lower jaw. C. Thyroid cartilage. D. Linea obliqua of thyroid cartilage. 1. M. Stylohyoideus. 2. M. Digastricus posterior. 3. M. Stylo-(pharyngo-) laryngeus. 4. M. Digastricus anterior. 5. M. Geniohyoideus. 6. M. Thyrohyoideus. 7. M. Sternohyoideus. 8. M. Omohyoideus. 9. M. Sternothyroideus.

must be remembered that it forms part of the natural action of swallowing in which the larynx is elevated much higher than ever occurs in singing. It may be observed in the case of the best singers and it is impossible to dogmatize on the

subject. However, excessive elevation of the larynx, like any excessive muscle action, may be injurious, and for that reason the so-called 'educative' lowering of the larynx is often advised. Tarneaud, **247**. On the other hand, in cases in which the increasing tension in the thyroarytenoid muscle produces a sphincteric closure of the whole larynx and the singer is unable to effect the transition to the next mode of vibration, the inhibition of the larynx elevation may be distinctly harmful. According to Tarneaud, after the transition the mode of vibration changes by reason of the action of the external laryngeal muscles. The sphincteric closure relaxes, the epiglottis rises and the pharynx volume increases. The expense of air increases while the quality changes to the deep tone of the 'covered' register. The phonatory vibration is more selectively transmitted to the palate and skull, giving rise to the sensation of head vibrations associated with the upper register. The closed period of the cycle becomes equal or less than the period of opening and recoil. The main action is contraction of the cricothyroid muscle, but at the same time the larynx must be held in posture by the supralaryngeal and infralaryngeal muscles. In the trained voice the transition to the second mode is so gradual that the sphincteric closure of the pharynx hardly occurs, since the singer has learnt to balance the diminishing efficiency of the internal larynx muscles by an increasing activity of the external muscles pulling on the anterior and posterior attachments of the cords. It is possible that some of the thinning action producing the sharper-edged appearance of the cords may be due to selective contraction of the variant fibres inserted into the edges of the cords and called the aryvocalis muscle. Strong, **360**, p. 9. In any case, the stiffness of the cords is increased and they vibrate with a higher natural frequency.

§ 17·6. **The Falsetto Voice.** The third mode of vibration of the larynx is described as that of the falsetto in the male or the head register in the female. In the male voice the falsetto is an additional pitch range above the normal compass

which involves an altered action of singing and is not always considered a desirable form of voice. The more or less acceptable form of falsetto in the male voice corresponds in mechanism to that of the head voice in the female, but there exists in the male voice an extreme form of falsetto which is

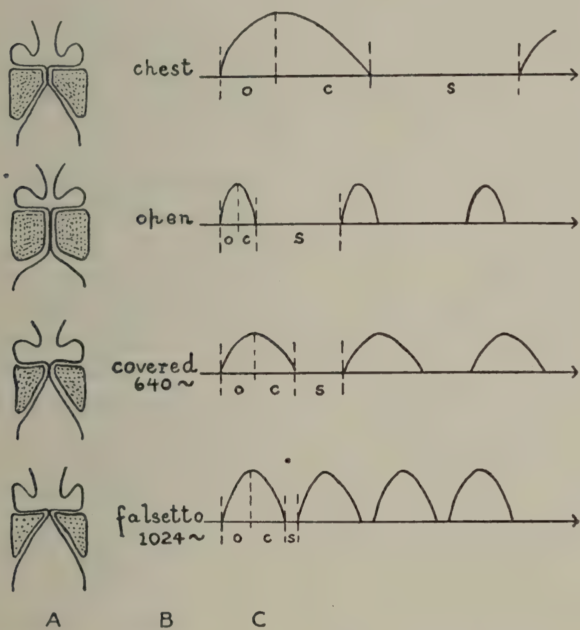

FIG. 15. The four modes of larynx vibration (Husson and Tarneaud). A. Schematic section of the vocal cords. B. Type of voice register. C. Scheme of the vibratory action. o. Opening phase. *c*. Closing phase. s. Shut phase.

not desirable as a singing form and is more equivalent to a high-pitched whistle. This latter action may correspond to the rare ‘ whistle ’ register in the soprano voice. To ordinary laryngoscopic observation the vocal cords in the falsetto (head) voice appear open all the time, but this is shown by

stroboscopic observation to be due to the optical effect of the relative periods of closure and opening of the cords. In the lower register when the period of closure is greater than or equal to the period of opening and closing, the mass appearance to the laryngoscopic observation is that of a closed glottis, while in the falsetto, when the closed period is much shorter than that of opening and closing, the appearance is that of an open glottis having an elliptical opening between the middle of the cords. According to Tarneaud, the third mode of vibration, used in the falsetto voice in males and the head voice in females, is an accentuation of the change from internal to external muscle action. The period of closure is much shorter than the period of opening and closing. The damping of the vocal cord motion is small and the thyro-arytenoid muscle is even more relaxed. The external muscles are more tense, the larynx is pulled higher up and the vocal cord edges are thinned out more. The cords touch over only about 2 mm. in depth, while the vertical displacement increases to about 1 or 2 mm. The extreme edge of the cord begins to move more obviously in the vertical direction.

§ 17·7. **The Whistle Voice.** Finally, the fourth mode of vibration described by Tarneaud, consists of the so-called 'whistle' register which is found only in soprano voices. In this case the vocal cords do not vibrate as a mass, though they are tightly closed together save for a part of the glottal length, usually in the middle or the anterior third, where there is an elliptical opening about 2 mm. in cross-section at the widest point. This opening comes at the point of least firmness of closure together of the cords and is somewhat similar to the lip aperture for ordinary whistling. Negus, **238**, p. 421. The stream of air passing through this opening causes the extreme edges of the cords to vibrate and produce sound in the manner of edge-tones. Naturally, the expense of air is greatly increased and the sound is greatly reduced in intensity though the auditory percept of volume may not be much reduced because of the greater sensitivity of the ear for the higher pitches. In the soprano voice the

whistle register is distinctive and does not permit of much clear articulation of speech sounds. The quality is shrill and flute-like. Relaxation of the thyroarytenoid and probably the interarytenoid muscles permits the vocal cord to be separated in this elliptical fashion at the point of least rigidity of the cord tissue. At the same time, however, the sphincteric contraction of the larynx increases so that the ventricular bands move closer to and press down upon the upper surfaces of the vocal cords, allowing only the extreme free edges of the cords to vibrate under the pressure of the air stream. This action occurs in the falsetto voice as well as to a certain extent in certain types of the vowel [i] pronounced on high pitches and with strident or shrill quality. Russell, **242**, p. 232.

Intensity

§ 18·1. The control of the intensity of phonation is largely a balance between several opposing or assisting factors, all being co-ordinated for voice. The major factor is the rate of flow of air expelled from the lungs, which is dependent upon the cross-section area of the trachea below the cords, the volume of inspiration and the muscular pressure exerted on the lung alveoli by the collapse of the thoracic cavity. This pressure must increase to a liminal force depending upon the circumstances before phonation can be produced. This air pressure has been measured in several ways, notably by a tracheotomy tube in the neck collecting the expired air, and varying figures are given. The liminal pressure for vowels is given at about 25 mm. Hg. and the maximal pressure ranging up to 60 mm. Hg. For consonants the pressure depends largely upon the type of consonant in dynamic terms, being largest for the explosion of stop consonants like [d], 35 to 40 mm. Hg.; 35 mm. Hg. for [p, t]; 30 mm. Hg. for [m, l]; 15 mm. Hg. for [r]; and 5 mm. Hg. for the fricative consonants [s, f]. In phonation the force of air pressure is opposed by the elasticity of the vocal cord material and the intensity of phonation is a resultant of these two

factors. It is probable therefore that for high intensities the closed period of the vibration cycle may be lengthened by reason of the increased resistance of the cord. In this way the action of the larynx is dependent upon intensity as well as pitch. When in the falsetto voice only a reduced surface area of the cord edge is presented to the air stream, the intensity of vibration falls. Finally, since the vocal system consists of the larynx source coupled to additional air chambers—the cavities of the pharynx, mouth and nose (when the velum is lowered)—the intensity of the resultant sound wave in outer air is a resultant of phonational intensity modified by the vibratory characteristics of these air chambers. If the articulatory organs are kept steady in a given position, the change in intensity is a result of action of the larynx. But in normal voice the continual changes in the apertures and volumes of the air chambers produce continual changes in intensity. As far as concerns phonation, the major control of intensity is the rate of flow of air from the lungs and consequently the pressure of air upon the under-surface of the vocal cords. The amplitude of the vocal cord vibration corresponds to the air pressure and is normally greater on low pitches than on high pitches. Moreover, it increases with intensity increase in the relationship of the law of proportionality of intensity to the square of the amplitude. Changes in the shape of the cords may occur in low intensities in the low register when the edges become more rounded. Russell, **242**, p. 221.

Quality

§ 19·1. As far as concerns the quality factor in phonation it is of great interest to note the evidence showing the prime importance of the larynx sound as the basis of all quality changes in voice. In the classification of speech sound the phoneticians have been too ready to assume that the larynx sound is static and invariable, and so the articulatory movements are made the basis of the classifications. However, study of the vocal cord action during speech shows quite

clearly that the larynx is in a state of continual manipulation and that the articulatory movements are only accessories to the simultaneous movements going on in the larynx. Eijkman, **276–7.** Certainly, when other factors are kept constant, those differences in quality, which distinguish the speech of one person from that of another, are due to phonational action. In cases of carcinoma of the tongue all the organ may be removed save for a stump, which is almost immobile. Yet it is reported that the patient was able to pronounce all the vowel sounds quite well. Negus, **238,** p. 412. In this case it must be considered that the larynx action was responsible in main for the recognizable quality of the vowel sounds, while certain consonants could be articulated by closure between the stump of the tongue and the pharynx wall. When attempts are made with models of the speech system in which a vibrating reed as a sound source is placed in the position of the larynx, or when a cadaver is used and the larynx is blown through, it is difficult to produce very recognizable speech sounds. In another experiment with a laryngectomized patient an Autodion (a source of pure tone of variable pitch) was introduced in place of and at the level of the larynx. Berger, **258.** The sound recorded at the mouth remained a pure tone without any vowel quality, whatever form the subject gave to his resonator cavities. Paget is probably most successful of all with his plasticine resonators with vibrating reeds as sound sources, but his success is limited to certain well-defined vowels [α, i, u] and the consonants [p, m, l]. In the final test his best performance is with his cupped hands as a resonator enclosing the reed as sound source. Paget, **160.**

§ 19·2. The distinctions of quality which differentiate the various types of singing voice in male and female are probably based ultimately upon anatomical differences. It is not easy to generalize upon this matter because the differences depend upon a sum of many interrelated anatomical factors which singly might not be significant. Generally speaking, for example in the male voices, the baritone has a heavier build,

larger larynx and longer and bulkier vocal cords than the tenor. The main means of discrimination remains that of performance in which the types of voice are distinguished by the respective compasses over which they can comfortably sing with good intensity. There is a means of measuring *in vivo* the length of the vocal cords which allows of a reliable classification on an anatomical basis. Trendelenburg, **377**. Between the contralto and the soprano the distinction is again one of quality and pitch range and certain anatomical distinctions can be made. The contralto singer is generally heavier built with a larger larynx than the soprano. Negus, **238**, p. 431. The quality distinctions between voices in singing are closely associated with the pitch ranges of the respective voices, since the low-pitched voices are naturally likely to be 'mellow,' 'dark,' 'resonant,' 'rich,' or whatever other adjectives are used to describe the baritone voice quality. Conversely, the high-pitched voices are likely to be 'shrill,' 'pure,' 'strident,' 'flute-like' or whatever other adjectives are used to describe the soprano voice quality. Since the component tones of a complex sound are almost invariably overtones and multiples of the fundamental pitch, there is an established physical relationship preventing the occurrence of low-pitched components as harmonics of a high-pitched fundamental, which would produce the effect of a baritone voice quality in a soprano voice. Such a case of abnormal voice quality is essentially due to abnormal conditions in the larynx producing vibrations of the ventricular bands and the mucous coating of the larynx. Conversely, a low-pitched fundamental may well have overtones reaching up into the high-frequency range and excited by some unusual mode of vibration of the larynx, thereby producing the tenor or alto voice quality. In practice it is found that, when the actual sounds of speech are kept constant, the differences in voice quality between individuals are not so great as commonly imagined. Such differences are often due rather to the individual manner of pronouncing speech sounds or the sequence of linguistic

patterns of the individual. Experiments in the reliability of recognition of voices do not show a high degree of reliability. McGehee, **199**.

§ 19·31. The main quality distinctions between voices are commonly described by a number of confused terms. The acoustic basis of classification has been dealt with in Chapter III. From the physiological standpoint there is great need of detailed study in a systematic way that would use all the available means of examination. Ordinary laryngoscopic study shows only those larynx movements slow enough to be observed with the unaided eye. Stroboscopy and high-speed cinematography alone will show up the details of the finer and faster movements of the larynx organs, which occur during all modes of phonation and voice. In the matter of quality distinctions between individual voices, it must be realized that all the other factors of pitch, intensity and duration must be kept as far as possible invariable in order to have only qualitative discriminations. It is probable that the available studies have shown up the general details of the larynx vibratory modes, yet the finer details of the action for particular speech sounds, modes of singing and personal voice quality are obviously subject to variation from person to person and from time to time. However, since there are certain bases of comparison between all voices and between members of the same language community, it is possible to state the broad lines of analysis without needing to define the personal factors. Thus, for example, the vibrato in a sung tone constitutes a factor common to almost all singing voices of accepted accomplishment. It is possible to state certain observed facts of the physiology of the vibrato which probably apply more or less completely to all voices. It is probable also that the difference between vowels are dependent upon larynx action for the main source of the quality content. For a given person pronouncing the eight cardinal vowels [i, e, ϵ, a, α, ɔ, o, u] on the same intensity and voice pitch, the larynx action varies for each vowel. Russell, **242**, p. 73ff. However, experiments prove that the

larynx conformation for the same vowel varies from one person to another. Such differences must be considered part of the individuality of the human being which evades close description and analysis.

§ 19·32. The low-pitched guttural or hoarse voice quality is frequently observed in cases of laryngeal catarrh, and accordingly has probably been most frequently studied. Apparently in these cases the ventricular bands are operative in the production of the voice quality, since they become swollen and flabby, and the pharynx volume is decreased by the constriction of the larynx and pharynx by approximation of the root of the tongue to the back pharynx wall. The vocal cords are very relaxed to produce the low pitch. Russell, **242**, pp. 50, 175. Conversely, the opposite quality—that of a harsh, metallic type, occurring in the 'voix blanche' in singing—involves altered action of the ventricular bands. They press down on to the upper surfaces of the vocal cords in such a way as to obscure the view of the cords from above. Probably in this way only the extreme edges of the cords are free to vibrate. Russell, **242**, p. 232. This action may be very similar to the edge tone voice produced in the whistle register. At the same time the pharynx is distended. In order to keep a good voice quality when singing the vowels [i, ɪ] on high-pitched, loud tones, the singer is obliged to make accommodations from the normal tongue position for these vowels by dropping the jaw and drawing down the tongue lower in the mouth. Russell, **242**, p. 91. This is taught as a singing technique to avoid excessively harsh quality on the high pitches.

The Thyroarytenoid Muscle

§ 19·4. The fine structure of the thyroarytenoid muscle has been described by several investigators. Histological studies have shown the presence of aryvocalis fibres set at 45 degrees to the horizontal run of the main muscle fibres and exerting a lateral pull on the elastic ligament of the edge. Strong, **360**, p. 22. By specific innervation of any group of these fibres

any segment or segments of the vocal cord edge might be placed under increased tension. It is even possible that the mucous coating of the cords might form an extension of the edge, which could vibrate at a very high frequency. Strong, **360**, p. 23. The presence of these fibres is not found in every dissection and may depend upon the skill and the determination to find them. Negus, **238**, p. 439. These fibres are only of micro-section and could exert only a feeble pull as opposed to the action of the main fibres and the external muscles. Strong, p. 19. Nor can it be assumed that the principle of isolated pitches in singing depends upon the selective action of the aryvocalis fibres, since the studies of performance in singing show that pitch accuracy in singing is variable, and that the so-called steady tones consist of the regular pulsation of pitch characterizing the vibrato, while the transitions from one pitch to another take place with a portamento. Moreover, the assurance of a given pitch of voice is the action of many muscles, including the thyro-arytenoid, and so the participation of the aryvocalis fibres must be only small in the total action.

§ 19·5. With advancing age certain changes take place in the structure of the larynx and produce characteristic changes in phonation. In the first place there is a progressive ossification and calcification of the larynx which sets in at about twenty years at three points—the postero-inferior part of the thyroid, the superior border of the cricoid and the base of the arytenoids. Portman, etc., **240**, p. 29ff. This action advances along the inferior edge of the thyroid and by about thirty-five years has invaded the lower third of the larynx cartilages. By about sixty years the whole larynx has become ossified. The thyroid and arytenoids show the ossification before the cricoid. The cartilage of the epiglottis rarely becomes ossified. Secondly, in old age there is a general loss of tonus in the stratified, squamous epithelium and the elastic connective tissue becomes degraded. There is a resulting enfeebled pitch control producing a quavery and tremulous tone. The general pitch of the voice tends to

rise again, and the quality of the male voice alters towards that of the female voice. The intensity range of voice diminishes and the voice often becomes hoarse by reason of the increased use of air and the frequent incomplete closure of the glottis by paresis of the adductor muscles. The laryngeal muscles become enfeebled so that the general accuracy of phonation is impaired. There is a strong tendency to strain and overpress the voice.

CHAPTER V

THE MECHANISM OF SPEECH

§ 20·1. In this discussion of the nature of speech no consideration will be given to questions of morphology, syntax and the history of the spoken languages. In general it is observed that even a short period of speech is a continuous activity which terminates when the speaker has completed the thought sequence that he desired to put into expression. In this sense speech is a sequence in which even the pauses have significance. It can thus be viewed as consisting of a number of successive units, some of which are distinctive and some non-distinctive, depending upon the characteristics of the spoken language. Bloomfield, **73**, p. 80. These distinctive features of speech constitute the recognizable entity and form the body of uniformity which brings together the speakers of one language into a speech community. The term ' Phoneme ' is applied to these distinctive features of a given spoken language, which are necessarily related to the general form of that language. Jones, **120**. Within a given language each phoneme is distinct from all other phonemes. But a phoneme found in one language may occur in another language and subserve a different purpose or hold a different meaning. The phonemes are merely distinctive features of sound, which the speaker hears and learns to produce and recognize in the flow of spoken language. The great majority of phonemes are the speech sounds—vowels, semi-vowels and consonants—but in all languages, and especially under certain conditions of linguistic development, the factors of intensity and pitch and duration may constitute phonemes equally as well as the factor of quality. The units of speech are the speech sounds which may be

considered as the product of distinctive actions of the speech organs. Menzerath, **121.** Since speech is a continuous activity as long as voice is produced, the division of a given period of speech into units is arbitrary and depends upon the principles of classification. By reason of the alliance of the spoken and written languages, certain conventions of the written language are represented in modified form in the spoken language. Accordingly in speech the component speech sounds are distinguishable rather as peaks of distinctiveness than as separate units. Gemelli, **87.** Certain distinctive groups of symbols in the written language have come to be accepted as representations of discrete thought-units. These written words are represented more or less uniformly in speech by groups of speech sounds which are only seldom spoken as discrete units. A sequence in the written language of a number of words brought together under specified circumstances is called a sentence and is terminated by a conventional symbol of finality. In speech, however, the corresponding flow of speech sounds may or may not terminate at the equivalent stage. It may be broken into segments of speech pronounced on one expiratory stroke and called a 'breath group.' So in speech the division into segments of the flow of sound production is largely dependent upon the phrasing of the given utterance. The duration of a given segment will depend upon the average intensity of voice during the segment as well as the thought content and expression of the spoken words. The more powerful speech must naturally be divided up into shorter breath groups, while quiet, monotonous speech may continue almost without perceptible pause for inspiration.

The Classification of Speech

§ 21·1. It has already been stated that the factors of pitch, intensity and duration may constitute phonemes in certain languages, equally as well as the factor of quality. The usual method of classifying speech sounds is on a basis of quality distinctions dependent upon the auditory percept

formed by the hearer for each sound. Such a classification is frequently referred to a quasi-theoretical, quasi-empirical physiological concept of the articulatory movements for each speech sound. Accordingly, the majority of the phonetic alphabets group the speech sounds according to the 'region of articulation' for each speech sound. In these alphabets the additional bases of classification are firstly the presence or absence of vocal cord vibration, secondly the use or non-use of the nasal cavity, and thirdly the degree and form of the obstruction of the air passage. A good example of this is the alphabet of the International Phonetic Association. For a speaker the control upon accuracy of articulation of each speech sound is partly kinæsthetic and partly auditory. Provided he articulates speech silently, that is without any production of sound, the kinæsthetic sensation of muscle motion and sensory epithelial contact must constitute the sole control. But in normal speech the auditory factor of control is most important, as is shown in the case of the deaf who have acquired speech before the onset of the deafness. In their case those details of speech movements which cannot easily be controlled by the kinæsthetic sensation—viz., the pitch and intonation, the noises of expiration, sibilant consonants, aspiration and voiceless consonants in general and the precise quality of the vowels—are the first to be slurred and faultily produced. As far as the hearer of speech is concerned, the control and comprehension of speech of others is largely dependent upon the auditory percept. Visual perception of the surface facial and neck muscles may contribute as much as 20 per cent. of the comprehension of speech, and the visual faculty may be cultivated by the deaf as a substitute for the failing auditory faculty. But when the hearer, in classifying the speech of others, attempts to correlate his auditory percept of the sound with the kinæsthetic sensation which comes from his own articulatory behaviour in producing a similar sound, he is liable to make a wrong judgment. He will be led to make suppositions of the physiological action on the part of the

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		Bi-labial	Labio-dental	Dental and Alveolar	Retroflex	Palato-alveola
CONSONANTS	Plosive	p b		t d	ʈ ɖ	
	Nasal	m	ɱ	n	ɳ	
	Lateral Fricative			ɬ ɮ		
	Lateral Non-fricative			l	ɭ	
	Rolled			r		
	Flapped			ɾ	ɽ	
	Fricative	ɸ β	f v	θ ð | s z | ɹ	ʂ ʐ	ʃ ʒ
	Frictionless Continuants and Semi-vowels	w | ɥ	ʋ	ɹ		
VOWELS	Close	(y ʉ u)				
	Half-close	(ø o)				
	Half-open	(œ ɔ)				
	Open	(ɒ)				

(Secondary articulations are sh

OTHER SOUNDS.—Palatalized consonants: ƫ, ᶁ, etc. Velari
(plosives with simultaneous glottal stop): p', t', etc. Implosive voi
or s, z). ʆ, ʓ (labialized ʃ, ʒ). ʇ, ʗ, ʖ (clicks, Zulu *c*, *q*, *x*). ɺ (a sou
i, y, u). ɜ (a variety of ə). ɵ (a vowel between ø and o).

Affricates are normally represented by groups of two consonan
etc.), or the marks ͡ or ‿ (t͡s or t‿s, etc.). ͡ ‿ also denote synchro
ally be used in place of tʃ, dʒ. Aspirated plosives: ph, th, etc.

LENGTH, STRESS, PITCH.— ː (full length). ˑ (half length). ˈ (
stress). ¯ (high level pitch); _ (low level); ˊ (high rising); ˏ (low r

MODIFIERS.— ~ nasality. ̥ breath (l̥ = breathed l). ̬ vo
close vowel (ẹ = a very close e). ̨ specially open vowel (ę = a rathe
(t̪ = dental t). ˙ palatalization (ż = ʒ). ˔ tongue slightly raised.
Central vowels ï (= ɨ), ü (= ʉ), ë (= ə˔), ö (= ɵ), ɛ̈, ɔ̈. ̩ (e.g. n̩) syllabic

FIG. 16. The International Phonetic Alphabet. (

PHONETIC ALPHABET.

, 1938.)

Alveolo-palatal	Palatal	Velar	Uvular	Pharyngal	Glottal
	c ɟ	k g	q ɢ		ʔ
	ɲ	ŋ	ɴ		
	ʎ				
			ʀ		
			ʀ		
ɕ ʑ	ç j	x ɣ	χ ʁ	ħ ʕ	h ɦ
	j (ɥ)	(w)	ʁ		

Front	Central	Back
i y	ɨ ʉ	ɯ u
e ø		ɤ o
	ə	
ɛ œ		ʌ ɔ
æ	ɐ	
a		ɑ ɒ

wn by symbols in brackets.)

ed or pharyngalized consonants : ɫ, ȡ, ʑ, etc. Ejective consonants
ed consonants : ɓ, ɗ, etc. ř fricative trill. σ, ϱ (labialized θ, ð,
nd between r and l). ʍ (voiceless w). ɪ, ʏ, ʊ (lowered varieties of

ts (ts, tʃ, dʒ, etc.). but, when necessary, ligatures are used (ʦ, ʧ, ʤ,
nic articulation (m͡ŋ = simultaneous m and ŋ). c, ɟ may occasion-

stress, placed at beginning of the stressed syllable). ˌ (secondary
sing) ; ˋ (high falling) ; ˎ (low falling) ; ˆ (rise-fall) ; ˇ (fall-rise).
ice (s̬ = z). ʻ slight aspiration following p, t, etc. ̣ specially
open e). ̫ labialization (n̫ = labialized n). ̪ dental articulation
tongue slightly lowered. ˃ lips more rounded. ˂ lips more spread.
consonant. ̆ consonantal vowel. ʃˢ variety of ʃ resembling s, etc.

Courtesy of the International Phonetic Association.)

speaker that are really based upon the articulatory actions of his own speech. This tendency has had a great influence on the discussion of the precise articulatory actions for given speech sounds. In any speech community, other than that of the deaf-mutes, the mass control of the accuracy of speech is almost entirely dependent upon the auditory percepts of speech formed by the hearers. Accordingly, provided the articulation of an individual produces auditory percepts sufficiently identical with the accepted mass standards for that speech community, the physiological movements going to produce that sound are not considered or observed. For any given speech sound the auditory percept is conditioned by time as well as by the sound wave. Thus for a stop consonant, for example, the whole plan of the sequence of implosion, holding closed, and explosion is significant and each part of the plan must agree within limits with the mass standard in order that the identity of the consonant shall be recognizable.

§ 21·2. In the usual classification of speech sounds the bases of classification are largely the physiological movements. The accompanying Fig. 16 illustrates the type of phonetic alphabet produced. The limitations of this alphabet can never include all the variant speech sounds of all the human languages, though some phoneticians seem to have had that object in view in constructing alphabets. For a given language the phonetic alphabet may be expected to indicate the mass standards of speech without reference to the individual variations. Such an alphabet may be considered to represent the framework of a given language but it does not show the way that the language functions. It makes no separation between the distinctive and non-distinctive features of speech. To show how a spoken language functions, how it operates in time as well as in physiological movement, the alphabet must indicate the phonemic structure of the language and take into consideration all four characteristics of sound, viz. quality, pitch, intensity and duration. Even this classification is limited and generalized, but it is

much more valuable and complete than the so-called phonetic alphabet in describing the real action of speech.

§ 21·31. **Intonation.** In considering in turn the remaining three factors of speech, viz. pitch, intensity and duration, it must be noted that the subject is too extensive for more than a brief illustration of each point. The factor of pitch change or intonation plays a greater or less phonemic part in all spoken languages. In general, certain emotional states, such as fear, joy, conflict, etc., produce symptomatic alterations of speech which result in a change of pitch. These are definite physiological accommodations dependent upon muscle tension in the chest, arms and legs in preparation for activity of some kind. Accordingly, in many languages the emotional content of the speech is indicated by the intonation pattern. In English, for example, the intonation pattern through a sequence of speech, consisting of a completed or final statement, rises to a peak near the important word of the sentence and then drops gradually towards the end when it usually falls abruptly. Conversely, in an incomplete statement or question, the intonation pattern rises steadily up to a maximum at or near the end when it may remain level or drop and rise again. A third type of sentence involving a supplement-question has an intonation pattern of somewhat similar type save that there is a lesser rise at the end. Bloomfield, **73,** p. 114. Naturally, there are many varieties of patterns in consequence of the varying emotional content and importance of the words. In languages of this type the pitch of any given speech sound is not especially phonemic, but the general pattern of intonation constitutes a subsidiary phoneme, capable of altering somewhat the meaning of the sentence as a whole. In other languages, for example, Japanese, Northern Chinese; Obata, **92–4,** Wang, **98,** Lithuanian, Serbian; Bloomfield, **73,** p. **116,** and African languages; Beach, **72,** Lukas, **89,** the intonation pattern associated with given words may be definitely phonemic; in North Chinese, for example, the four tones of utterance of a given set of speech sounds may form radically different thought content

and meaning. In Cantonese these tones are extended to nine. Wang, **98**. This use of pitch as a primary phoneme is a consequence of the artificial nature of the written and spoken languages of these communities. In Chinese the deliberate and careful preservation of unchanged symbolic representations of thought patterns over a long period of time has resulted in a scarcity of symbol patterns. Accordingly, the same symbol patterns used with the modifications of pitch change have provided an increased range of representations of thought. Since pitch changes cannot be adequately represented in the written language, in the written form the context has become the means of separating the variant meanings.

§ 21·32. The intonation pattern of speech may be recorded and measured very accurately by an ingenious electrical method. Obata, **31**. By this means the pitch change of voice may be photographed on paper on which the ordinates of musical pitch have been marked. This is distinctly preferable to the inaccurate judgment of pitch by the unaided ear. In view of the known distortion tendencies of the ear and the fact that pitch is dependent upon the personal auditory capability of the individual, the auditory method is at best only an approximation. In particular, in these auditory judgments of pitch the factor of duration affects the judgment so that pitch seems to fall with shortened duration. Stevens and Davis, **47**, p. **101**. In all studies of intonation in speech careful attention must be given to the phonemic importance of the various speech sounds, as, in the African Sudanese languages, the relative pitch-level of the word itself. The factor of contrasting pitches constitutes an important element of Chinese verse. Sapir, **81**, p. **246**. In transferring from a native to a foreign spoken language the intonation patterns of the native language are often retained in the foreign language, even when the correct pronunciation has been carefully learnt, thus producing an incongruity of sound. Too little attention is paid in teaching foreign languages to the subsidiary phonemic importance of intonation.

§ 21·4. **Intensity.** The consideration of the factor of intensity raises the problem of stress and syllabic division in speech. In speech there may be observed a tendency to subdivide lengthy groups of speech sounds into smaller sequences which are uttered with a sense of the unity of the sequence. These subdivisions, which may be short words or sections of longer words, are called syllables, and there is much discussion of the principles by which syllabic division may be governed for a given spoken language. It may be noted that for a given person the manner of syllabic division is part of the non-distinctive elements of language. The principle may be based upon relatively pure dynamic considerations, and in this theory the syllable consists of sequence of speech sounds pronounced with a pattern of increasing and then decreasing muscle tension. Fouché, **74.** Another definition bases syllabic division on the frequency of occurrence of peak sonorous sounds ; that is, there are as many syllables as there are peaks of sonority. Bloomfield, **73,** p. 120. In any succession of speech sounds some are more sonorous than others, and thus vowels are more sonorous than consonants, nasals, trills, and lateral consonants more than stop or continuant consonants, continuants more than stops and voiced sounds more than unvoiced. The sonority of a speech sound is an expression of its loudness or carrying power. If syllabic division depends upon the relative loudness of phonemes, then it can be accentuated or flattened out by changes in intensity. Bloomfield, **73,** p. 125. In English, the pattern of sonority admits of rather wide ranges of change, but in French the range is restricted and so each syllable is reinforced by a slight increase of intensity of utterance for the distinctive sound. Fouché, **86.** The inherent intensity of a speech sound determines its factor of stress which may be phonemic in certain languages. The phonemic importance of stress is not so radical in single words as the other factors of pitch and quality, but in sentences the stress pattern may constitute secondary phonemic differentiations. In English there is a tendency to stress the important words of sentences,

and by this means to reinforce the clarity of the meaning. Malone, **90**. As a result, the sounds of unstressed syllables become degenerated or weakened in quality and duration. In English, the vowels of unstressed syllables degrade towards the quality of the vowel [ə]. The final, unstressed vowels of Old English tended to be lost in Middle English. In other languages the pattern of stress is not distinctive but acts only as a kind of conventional gesture. Bloomfield, **73**, p. 111. The intensity of utterance and the loudness of speech can be recorded and measured accurately by various means. In a method rather similar to that for the study of pitch with which it can be combined, the variations in loudness are represented by a wavy line on photographic paper on which ordinates of intensity can be marked. This is of course an absolute measure of intensity and not therefore an exact indication of the auditory percept of loudness. The auditory percept of loudness and therefore of stress formed by the hearer depends upon his ear and the duration of the speech sound. Long sounds of a given intensity tend to be judged louder than short sounds of the same intensity. Very short speech sounds may be judged quite feeble when they are of average intensity.

§ 21·5. **Duration.** The factor of duration plays a secondary phonemic part in several languages. Thus in German the so-called ‘ tense ’ vowels [i, e] are longer than the ‘ lax ’ vowels [ɪ, ɛ]. This distinction is not phonemic in duration but in quality. Quite frequently in languages there occur long consonants formed by the apposition of double consonants: for example, Finnish [kɑppi] and English [gʊddei] ‘ good day,’ [ɹættɹæp] ‘ rat trap,’ [sækklɔθ] ‘ sack cloth,’ and so on. In these cases the duration is not phonemic, but in ‘ Bankon,’ belonging to the Bantu group of African languages, duration assumes the function of a semantic form. Miller, **91**, p. 129; Westermann, **99**. There is, for example, a definite length difference, varying from 1–2·7 to 1–4, between short and long vowels in monosyllables. Thus for example in this African language :—

hɔ̃ (short) 'boa constrictor'; hɔ̃ (long) 'plenty.'
χà (,,) 'fish trap'; • χà (,,) 'full."
hɛ̀ (,,) 'to drag'; hɛ̀ (,,) 'flame colour.'

Through the history of the English language the duration of a phoneme has often depended upon the nature of the following phonemes. Generally long vowels remained long and short vowels were lengthened in open syllables, that is, in positions in words in which they terminated the syllable in question. In closed syllables, terminating with a consonant, the long vowels were shortened and the short vowels persisted short. Thus Old English [klɛ : | nə] became Modern English 'clean' [kli : n], as contrasted with Old English [klɛ : n | zian], which became Modern English 'cleanse' [klɛnz]. Since there is a minimum duration of a sound necessary to the understanding of that sound, it is probable that the very short speech sounds, like unstressed vowels in English, are barely heard at all. Most probably they are guessed at by the hearers from the context of the sentence. The actual duration of speech sounds may vary within wide limits. In English, the vowel [ɪ] of [pɪn] 'pin' may last only about 1/30th second, or 3 cycles on a voice pitch of 100 cycles, while conversely the vowel [i :] in the phrase [—ti :] 'have some tea' may last as long as half a second. The duration of a stop consonant depends on its position in the word and the nature of the surrounding phonemes. It is longest in the final position, shorter when followed by a voiced consonant and shorter still when followed by a voiceless consonant. In most languages these variations are not distinctive or phonemic but are the results of the continual interaction of a speech sound upon the contiguous speech sounds. The efficiency of speech is often reckoned as a function of the time occupied by speech in proportion to the clarity of the communication. Variations in speed and duration are closely dependent upon variations in energy. Movements involving much use of energy can be made with greater speed but last proportionally less time than movements of small energy.

Articulation

§ 22·1. In the discussion of the articulation of the various speech sounds it must be remembered that the statements of physiological movement can only be generalizations and that the auditory effect of a given sound may be produced by different articulatory actions in different individuals. Thus persons with the tongue immobilized or surgically removed in carcinoma, can substitute for the stop consonant produced by closure between the tongue and palate by an occlusion between the root of the tongue and the pharynx wall. The ventriloquist is obliged to substitute a pharyngeal stop consonant for the labial stop consonants, which he cannot articulate without betraying himself. Cleft-palate patients often learn to produce a stop consonant between tongue and velum in an attempt to produce the pressure necessary for the explosion of the consonant and prevent the air escaping *viâ* the cleft into the nose. In these cases the acoustic effect is accepted if it is sufficiently near to the accepted mass standard, even though the physiological movement be very different from the normal type. It is true, however, that as finer and finer distinctions of quality are possible by training of the ear, the possibility of successful substitution in this way become more difficult and more easily detectable.

§ 22·2. The articulation of speech sounds may be discussed under three headings: the degree of occlusion of the oral passage, the degree of occlusion of the nasopharynx, and the region or regions of the narrowing or occlusion of the oropharynx. The distinction between voiceless and voiced speech sounds is a matter of phonation and not of articulation. Firstly, the degree of occlusion of the oropharynx may take one of three stages. There may be a complete stoppage for a brief period with a consequent rise in air pressure behind the region of occlusion and a more or less audible escape of air after the release of the stop. This is the case of the stop or plosive consonant and the closure may be produced in any part of the oropharynx and mouth from the lips to the

larynx. The temporal pattern of a stop consonant is normally successively implosion, holding and explosion. In the initial position in a word the implosive phase is often omitted by beginning with the closure. In the final position the explosion may be weakened or omitted. The force of the explosion varies with individuals and languages and may constitute a phonemic distinction as in Sanskrit, which has four phonemes, viz., [p], [p] with explosion, [b], and [b] with explosion. Similarly in Northern Chinese, [p] and [ph] are phonemes. The area of closure may be duplicate or triplicate as in the cases of the double stops [gb] of African languages or the triple consonants, such as [stɹ] in English. The comparative intensities and durations of these stop consonants can be studied from kymograph tracings of the mouth air stream. Rousselot considered that the volume of air exploded was inversely proportional to the force of the occlusion. Rousselot, **117, 1**, p. 241. He found the following order of increasing volume: [ba, pa, ka, fa]. In German, Dutch, and Flemish there is a tendency for glottal stops to be formed simultaneously with the occlusion of the stop consonants, but this is not the case in French. Borel-Maissony, **308**, p. 34. The action of explosion may be abrupt or gradual so that a definite quality distinction is produced between the two types. The stop consonant may merge without explosion into a continuant or another stop consonant. The contact action of the stop may be repeated rapidly at a rate which produces a throbbing sound characteristic of the 'rolled' consonants [ʀ, r]. This is generally of two types: firstly, a rapid tapping of the tip of the tongue against the hard palate in [r] and, secondly, a rapid contact and separation of the back of the tongue and the uvula as in [ʀ]. Alternatively, the stop consonant may be produced by a single rapid contact, as in the single tap of the tongue against the hard palate.

§ 22·3. **Nasal Sounds.** The occlusion or opening of the nasopharynx is greatly dependent upon linguistic tendencies. In Standard English it is opened only on the nasal consonants

[m, n, ŋ]. In French it is opened only on the nasal consonants and the nasal vowels [ɑ̃, ɔ̃, ɛ̃]. In certain resonant bass voices the nasopharynx is open most of the time in speech, yet the open nasopharynx does not necessarily produce nasality of voice. Russell, **242**, p. 18. The so-called nasal 'twang' of New England American speech is often the result of violent contraction of the larynx with an additional narrowing of the larynx aperture. Russell, **242**, p. 239. This effect may be copied by laying the hand horizontally above the hyoid bone and pressing forcibly and suddenly upwards and backwards. Paget, **160**. During the holding of a non-nasal stop the nasopharynx is tightly closed off, but during other speech sounds the occlusion may be relaxed somewhat so that the uvula is not pressed back so firmly. Thus in current English, any vowel may be nasalized in the proximity of the nasal consonants, or when the speaker is in a tired state. The use of the nasopharynx in singing is subject to a great deal of variant opinion. The rigid paranasal sinuses—the maxillary, frontal and sphenoidal—play no part in the production of voice. Negus, **238**, p. 440 ; Seth and Guthrie, **172**. Cats and sea-lions have no paranasal sinuses yet have good voices. The giraffe has well-developed sinuses yet has no voice. The ostia of the sinuses in the human being are so small and tortuous that the possible entry of air is very doubtful.

§ 22·4. **Continuant Consonants.** The second stage of narrowing in the oropharynx is that of the continuant or spirant consonant. In this case the narrowing is sufficient to produce audible air friction of varying intensity, having component frequencies characteristic of the continuant consonants. These intensities and frequencies vary somewhat in the individual speaker and language as a result of the proximate speech sounds and the mass standards of the speech community. In English the consonants [ɹ, l, ʃ] are generally more intense than the consonants [θ, f]. The degree of narrowing may be reduced so that the spirant consonantal position tends to merge into the more open

position for the third stage: that of the vowels. Thus in English the consonants [j, w] may be semi-consonantal or semi-vocalic in quality according to the type of the contiguous phonemes. In American English the vowel tends to merge with the following consonant [r] into a semi-consonantal sound [r̥]. The frictional sounds are generally produced by surface vibration of the tongue or pharynx walls, but may also be the product of vibration of the mucus coating the vocal cords, the ventricular bands or the ventricle. Russell, **242**, p. 47, p. 237. These frictional sounds are likely to be transient and inharmonic to the fundamental pitch of the voice and are very variable in quality. The spirant may frequently combine with a preceding or succeeding consonant, so that the explosion of the stop consonant or the implosion, depending upon the relative position, may be incorporated into the spirant. It is noteworthy that the oral spirant and stop consonants may occur in voiced and voiceless pairs, though any given language may not have all the members of each set. Pienaar, **95**. This occurrence of the pairs of consonants is obviously the result of the audible contact sound of air friction, characteristic of these sounds. They are audibly distinctive in the unvoiced state without the need for voice. Conversely, the third stage—that of the vowels—is a narrowing acting only to accentuate or weaken components of the larynx sound produced by phonation. Thus for the vowels the phonatory sound is necessary for the audible percept and so all the vowels are voiced. It is true that whispered vowels can be articulated without phonatory vibration of the larynx, but these are of a minimal audibility and are universally classified as subnormal speech sounds.

§ 22·5. **Vowels.** In this third stage of narrowing—the stage of the vowels—the distinction is largely one of a selective modification of the phonatory sound wave. It is true also that a great deal of the modification of the phonatory sound wave for each vowel takes place in the larynx by laryngeal accommodation, and so the action of the supralaryngeal organs is of much more subordinate order than in the case of

the spirant and stop consonants. Accordingly, there is much more variation in the articulatory actions for the vowels than those for the consonants, and most of the conflict of the phoneticians has centred around the articulatory actions for vowels. It is now evident that, since the auditory percept is the major control of voice quality, the exact region or regions of sphincteric narrowing of the speech passage are not very significant as long as the auditory product is kept relatively similar to the mass standards for the vowel in question. It must be remembered also that the significant factors for vowel articulation are not the height of the tongue in the mouth nor the amount of retraction of the tongue but the consequent volumetric expansions and contractions of the speech cavities. The significant factors are the volume of air in one of these cavities, which is slightly pent up behind a constricted aperture, as well as the cross-section area and length of the aperture. Accordingly, different regions of the speech passage are likely to produce different outline shapes of these apertures. Thus, for example, a narrowing in the mouth by the raising of the tip of the tongue towards the teeth ridge or the hard palate will produce a cavity aperture of relatively short extent, while conversely, a narrowing of the pharynx by elevation of the back of the tongue towards the soft palate produces constriction of a long extent.

Articulatory Movements

§ 22·6. The articulatory actions of the various organs—tongue, velum, pharynx constrictors, lower jaw and lips—are significant not so much in themselves as in the acoustic effect produced on the larynx sound. During speech the organs are in a state of constant motion, and it is not really correct to say that for the articulation of a given speech sound the organs take up a given position. It is rather the case that they move to a given position and then begin to change position immediately in anticipation of the succeeding speech sound. Consequently the conventional phonetic alphabets in their classification of speech sounds by the regions of

articulation can indicate only the sequence of climaxes, as it were, in the continuous process of articulation. The concept of articulation must include the temporal and dynamic as well as the mechanical factors of speech. The conventional classification of articulatory positions is shown in Fig. 16 This classification is valid as long as the limitations of the method are kept firmly in mind.

§ 22·7. The articulatory movements for the vowels are less well-defined than those for consonants, but certain broad distinctions can be made. The vowels of European languages may be grouped into four classes: firstly, the so-called 'front' vowels [i, y, ɪ, e, ɸ, ɛ, œ, æ] and the variants; secondly, the so-called median vowels [ɑ, a] and their variants; thirdly, the so-called back vowels [ɔ, o, ʊ, u] and their variants; and finally, the so-called indefinite vowels [ə, ə :] and their variants. For the front vowels the articulatory pattern is that of a narrowing in the front of the mouth between the blade of the tongue and the hard palate, with widening of the pharynx and an open larynx. The acoustic effect is an accentuation of the high overtones of the larynx tone and surface frictional vibrations. For the median vowels the main action is a constriction between the epiglottis and the pharynx wall with a relatively open mouth and lip position. The acoustic effect is that of a relatively unaltered glottal tone with an increase of intensity. For the back vowels the factor appears to be an increasing constriction at the lips with an increased narrowing between the tongue and the soft palate and a progressively larger pharynx cavity. The position for the indefinite vowels is essentially that taken up by the tongue in a period of rest, with the cavity opening about the same width all the way from the larynx aditus to the lip aperture. These are the vowels towards which the other vowels of a spoken language degrade in hurried or careless speech. It must be noted also that a narrowing of the lip aperture may constitute an additional factor in the articulation of a vowel. Provided the jaw opening is narrow enough to allow the orbicularis oris muscle to produce an

appreciable narrowing of the lip aperture, this action, which is called 'rounding,' may produce a quality change in a vowel. Theoretically any vowel may be produced with some degree of lip-rounding in addition to the articulatory action elsewhere in the speech system, so that for each region of articulation there would be a series of vowels produced with no lip rounding, with average lip rounding and with excessive lip rounding. In practice, however, in any given language only a part of this total range of vowel possibilities is to be found. Stirling, **96.** Moreover, since phonemic classifications give at best only an approximate analysis of the full physiological picture for each sound, vowels described by the same symbol may possess different degrees of rounding in different spoken languages or in different individuals. The accurate 'phonometry,' or measurement of all the dimensions of the speech system for a given speech sound, shows the possibility of considerable variation in articulatory action for the acoustically identical speech sound pronounced successively by the same person or by successive persons. Zwirner, **119, 400.**

Speech

§ 23·1. The operation in connected speech of the four factors of quality, duration, intensity and pitch can be discussed only in brief fashion at this stage. Firstly, the factor of quality is largely associated with the personality of the speaker. It forms the basis of the recognizable meaning of the words and conveys the individuality of the speaker. The great complexity of language forms arises out of the possible great variability of this factor of quality. The individual words of speech are recognized in a mass impression by the brain as they coincide with auditory patterns of sound quality stored up in the experience of the person. Certain patterns of speech quality become associated with certain concepts of geography and race, so that the individual may be classified by his speech as coming from a given geographical region. As yet little correlation has been found

between the climatic factors and linguistic forms, and it is doubtful if the discussion can be carried very far along these lines.

§ 23·2. **Duration.** The factor of duration appears in linguistic structure as a basis for considerable variability of speech sounds. Many European languages differentiate between long and short vowels. Changes in the duration of speech sounds may be associated with factors of temperament. Individuals of an excitable, highly-strung type, whose thought process is liable to a great deal of over-activity and agitation by reason of their temperament, are liable to adopt a rapid and hurried mode of speech. Conversely, those whose occupation tends to slow down thought processes and restrict the scope of intellectual activity tend to be slower in speech and more deliberate. This is, of course, only a generalization, since either type of speech may be adopted for a deliberate purpose. By reason of these factors an audience tends to form from the temporal pattern of a given speech style a concept of the temperament of the speaker.

§ 23·3. **Intensity.** The operation of intensity changes in connected speech is an interesting indication of the complexity of speech actions. An aggressive, dominant speech passage shows a greater range of intensity than a restrained, calm statement. The intensity range employed by a public orator is greatly extended above that of ordinary conversation. For the purposes of radio broadcasting restraint of intensity change within limits is desirable by reason of the limited range in electrical propagation. Audiences are very liable to be swayed by the effects of the intensity range used by the speaker. The constant reiteration of a forceful statement in a loud voice may build up an excitement in the audience even though the meaning be obscure. The phonemic importance of intensity is only secondary in European languages, in which the intensity factor comes into play only when two or more speech sounds are joined together in a sentence. The force of the utterance may be emphasized by gesture, but this rarely goes beyond a vague picturization.

§ 23·4. **Pitch.** Finally the general operation of the pitch factor in spoken language is largely dependent upon the muscular activity which may arise in sympathy with certain emotional states. Thus in fear or apprehension, the larynx muscles, especially the extrinsic muscles, tend to contract, and consequently the natural pitch of the voice rises. However, beyond this general statement, the complexity of linguistic forms has tended to obscure this more primitive reaction, so that it is not possible to carry the analysis much further. Pitch and intonation patterns are very closely referrent to the language in which they are used.

CHAPTER VI

THE SINGING VOICE

§ 24·1. In the consideration of singing it is important to distinguish the four contributory stages in the singing process. These are in sequence, firstly, the composition ; secondly, the singer ; thirdly, the performance ; and finally, the audience. In this analysis only the first three factors will be dealt with. The original composition forms the pattern of song which the singer renders in his own individual interpretation. A song may be defined as a short metrical composition whose meaning is conveyed by the combined force of words and melody. Grove's Dictionary. Save in the accident of direct personal contact between the composer and the singer, the original composition is transmitted to the singer in the visual form of the written music and words. Accordingly, every performer is liable and indeed required to interpret the original in a manner peculiar to himself. When these modifications are considerable and clash with the accepted musical standards of the period, the performance is condemned. On the other hand, the performance may improve upon the original. Quite often the composition may require a greater pitch range or a wider intensity extent than can be produced by the singers of another era, and then the composition is difficult to render. Mozart. ?

§ 24·2. In its plainest form, dissociated from the frequent, accompanying factors of costume, scenery, action and visual expression, the song is conveyed to the audience solely by the sound waves. Hence the emotion and thought not expressed directly by the words must be conveyed by one or more of the four major characteristics of sound : frequency, intensity, duration and quality. Some parts of a song may consist only

of melody where the words are really unimportant, as in the case of coloratura soprano solos. But in the average song the contributions of words and melody are about equal. Certain singers tend to overlook the fact that words are of any importance. The average song is at best a compromise between the conditions imposed by the factors of speech and those of singing. Frequently, the words may have been composed separately from the melody so that one may have been moulded to fit the other. Since singing is an almost continuous production of sound, interrupted only by the pauses for inspiration or for grammatical phrasing, it results that any speech sound, which interrupts the continuity of song, produces a conflict between the words and the melody. Thus the voiceless stop or continuant consonants in the words accompanying the melody are frequently changed in performance to voiced speech sounds, or are greatly weakened or omitted. A language, such as Italian, in which the proportion of these voiceless speech sounds is small, is more readily adapted to the requirements of singing than a language, such as German, in which that proportion of voiceless speech sounds is much higher. Accordingly, an English audience may be pleased with an opera sung in Italian even though the words may not be understood. The melody is the source of the pleasure. Furthermore, in individual words, syllables ending in a vowel (open syllables) are more easily prolonged than syllables ending in a consonant group (closed syllables). Italian abounds in open syllables, and singing in the legato style is accordingly much easier in this language. Those languages having a high proportion of speech sounds which check the flow of phonation are more suited to the staccato or recitative styles. This contrast is at most only a generalization, since for each language there may be found many styles of singing. But there is a general consensus of opinion that Italian is a language eminently suited to the needs of singing. In translating the words of a song from one language to another, difficulty is often experienced in fitting the new words to the original melody.

In this case, the song must be studied from the viewpoint of the singer, who cannot be expected, for example, to hold a high-pitched tone on a stop consonant like [p]. All too frequently, the composer is liable to write his melody on pitches outside the normal compass of the singers for whom it is intended. Mozart. In this case the median of the pitch range of the song is above the tessitura (the median of the compass) of the singer. These songs may be performed adequately only by the specially gifted singers, and by the others only at the expense of quality or even the health of the vocal organs. There are rare cases of singers capable of rising to **c4** (2,048 cycles), or having a compass of four or five octaves. Semon, **351**; Réthi and Froeschels, **336**, p. 333.

§ 24·3. There is a third factor in the composition which is of increased importance in modern songs, but is not strictly necessary to the composition. This is the factor of accompaniment, whether by a single or many instruments. The accompaniment is able often to help the singer to keep to pitch and tempo, to conceal the inspiratory pauses, or to augment and accentuate the performance. Furthermore, the accompaniment may constitute an integral addition to the song in the form of linkages and introductions. Accompaniment approximates more closely to the original composition than does the performance of the singer. Yet it can be greatly varied at will in the arrangements of the original score.

Composition

§ 24·4. In the detailed consideration of the compositional manipulation of the four major characteristics of sound, it is to be noted that only quite recently have we been able to study in a scientific and objective manner the actual composition and performance of a song. 'Iowa Studies in Psychology of Music,' 102. The objective study of singing has been given a lead which should be followed up steadily. Though the subject is as yet explored only in a few directions, it is already possible to make certain definitions about the

actions of the variables—duration, intensity, pitch and quality—in composition and performance. The following discussion is largely based upon a recent excellent analysis of the rhythmic factors in singing. Seashore, H. G., **350**. In the matter of duration the musical score gives fairly definite and inflexible indication of the note and rest values, and metre and phrasing do the same for words. In most European languages the metrical system is formed of a variety of stress patterns, and hence in these languages the actual durations of the component speech sounds of songs are less important than the intensity of utterance for each sound. The stress pattern does, however, react upon the duration of the syllables, and in these languages the performance of the singer will exhibit patterns of over- and under-held notes depending upon the patterns of more or less stress in the metre. The pattern of phrasing is much more variable, and a long phrase in the composition may be broken in performance by an inspiratory period or a rest pause required by the metre. Obviously, an excessively intense performance may necessitate more inspiratory pauses than the less intense performance indicated by the score. For the legato style it is desirable to have a uniform system of phrasing with phrases of approximately equal duration. In the staccato style more variation is permissible.

§ 24·5. **Intensity.** The compositional handling of intensity is subject to great variation. The conventional musical marks of intensity cannot indicate absolute standards, but refer only to a scale of intensity change based upon a median which is peculiar to the singer. This scale is less satisfactory than the decibel scale in use in all acoustical discussions of intensity, since the latter has at least a mathematical integration. Accordingly the composer is at a loss to indicate clearly absolute intensity of performance in his composition and the singer is at great liberty to vary them. The composer is able to indicate only average levels or changes in levels of intensity, and he tends to rely upon the interpretative capacity of the singer to express the emotional content of the words

and situation in the form of suitable intensity variations. The intensity variations in such a case tend to follow the general pattern of physiological reactions to psychological processes. Thus a highly demonstrative or active situation involving speech tends to bring about an increased intensity and a raised pitch of voice. Within and around the two major conditions of emotional states the composer is able to build up a wide variety of modifications which the singer interprets more or less faithfully in the performance. His success depends upon his power of recreating in himself the emotional concepts formed by the composer. Here, too, since a song is a combined product of composer and singer, the performance may excel the original composition. The accompaniment is naturally more bound to comply with the definite limits of intensity than is the singer; it serves to accentuate the intensity patterns produced by the singer. The range of intensity indicated in composition is accordingly only approximate, and in performance will be determined rather by the capabilities of the singer. In performance the average singer in legato style is capable of an intensity range of 20 decibels, but, naturally, in intense concert style the range may be greatly extended.

§ 24·6. **Pitch.** In the matter of pitch the skill of the composer is most clearly displayed. The melody is determined by his choice of pitch change, intervals, repetition and sequence. His control of counterpoint and harmony is dependent largely upon his musical aptitude and training and the consideration of the singer's capabilities limits largely the range of pitches available. The words of the song possess a native pattern of intonation dependent upon the nature of the language. It is desirable that the melody should accentuate rather than obliterate the intonation pattern of the words. This factor explains much of the difficulty of fitting words to melody for which they were not intended. Again the metres of many languages are formed of definite stress patterns which give rise to similar intonation patterns in the words. Hence peaks of duration, intensity and pitch may coincide on the

same note at a stage in the phrase at which the singer is incapable of producing the vocal effort required. The extent of a portamento will depend mainly upon the powers of the singer. The use of ornaments and figures in the score will depend largely upon the style of composition and the accompaniment. The precise character of the vibrato, trill and tremolo is largely a personal factor of the singer, though the main details of these ornaments are fixed.

§ 24·7. **Quality.** The handling of sound quality as a compositional factor is restricted mainly to the form of the words and the accompaniment. The emotional content of the words will bring about certain quality changes determined by the nature of the language ; while the type of accompaniment, whether, for example, that of pipe, string or wood-wind, may be varied to accentuate the effect of the words. Moreover, on the high pitches the singer is often obliged to modify the quality of the words by reason of the changed mode of vibration of the larynx. For the vowel [i], for example, the voice quality tends to become more shrill on the higher pitches, unless the singer makes an accommodation by opening up the front cavity. The falsetto voice may have to be used to reach pitches above the normal compass. Frequently at very high pitches the quality of the sound together with the feelings associated with the production of high-pitched sounds will form the main indication of the emotion when clear articulation of the words is no longer possible.

The Singer

§ 25·1. In considering the second agent in the singing situation—the singer—it is advisable to clarify immediately the manner in which the singing voice is defined and classified. Voice is classified according to the anatomical, physiological and psychological characteristics of the individual. These are firstly, the morphological type, then the general physique, the form of the larynx (especially the vocal cords), the dimensions of the vocal cavities, the vocal powers of compass,

quality and intensity, and the temperament and faculty of emotional expression. The male voices are classified generally into bass, baritone and tenor. The alto is often a variant form of the male voice, having qualities and the compass of the female contralto, or even soprano. The female voices are classified into contralto, mezzo-soprano and soprano. These classifications are based mainly upon the distinctions of the pitch ranges of the respective compasses. The average classification is shown in Fig. 12. In terms of scientific pitch the average ranges are as follows :—

Bass . . .	76 to 256 cycles
Baritone . . .	96 to 384 ,,
Tenor . . .	140 to 512 ,,
Contralto . .	217 to 665 ,,
Mezzo . . .	256 to 768 ,,
Soprano . . .	384 to 1,024, or 2,048 cycles, in exceptional cases

The frequency range for any given voice is probably largely determined by the dimensions of the vocal cords, which may be measured accurately *in vivo*. Trendelenburg, **377** ; Zimmerman, **398**. The vocal cord length in the child increases slowly up to the period of puberty at the age of eleven to fourteen years. The average development in this growth is from about 4 to 9 mm. in the male and from about 3 to 8 mm. in the female. At puberty in the male the cord grows rapidly about one-third longer and increases in bulk and breadth over the pubertal period of some six months. An average adult length of the cord is 17 mm. in the male and 12 mm. in the female. Since the larynx action varies with the production of higher and higher pitches a quality discrimination is associated with this classification on the basis of compass. Thus in the male voice the bass, baritone and tenor voices are distinctive for quality and similarly in the female the contralto, mezzo and soprano voices are distinct in quality. It is difficult to separate this quality discrimination from the concomitant pitch distinctions which

condition it. However, abnormal quality changes in the direction of those of the opposite sex are very noticeable and usually betray the incidence of some disorder.

§ 25·21. **Ornaments.** A singer can learn to have at his disposal certain ornaments of voice which are accepted as musically pleasing. These ornaments are successively, the vibrato, the trill and the tremolo. In the treatment of the performance of singers it will be shown that a singer rarely keeps to true pitch for any length of time. The deviation from true pitch may be small and is often in the nature of a periodic variation above and below the true pitch at a rate which is fairly constant at about 6 to 7 per second. This is the so-called vibrato, which is a relatively recent development in singing technique, since in the old Italian school a steady pitch was greatly admired and cultivated. The vibrato consists of a periodic, symmetrical variation above and below the pitch level at a rate of about 6 to 7 per second and over a pitch range of a musical semitone in all. A slowed down and uneven form of the vibrato is stigmatized as the 'wobble.' This is often produced in the initial stage of learning the vibrato. The rate of the vibrato is evidently determined by the faculty of the ear that, as a periodic alternation of two pitches is speeded, a fusion of the two pitches into a single pitch, having a changed quality, occurs at the rate of 6 to 7 per second. Stevens and Davis, **47**, pp. 236–8. The pitch extent of the vibrato is kept within the limits, outside which the percept would be that of two separate pitches as observed in the trill. The dynamics of the vibrato are also conditioned by the structure of the larynx. The rate of 6 to 7 per second occurs quite often in speech movements, since it is the average speed of movement of the articulatory organs, of the tongue, soft palate and lips, the average rate of spasms in stuttering and the rate of many types of clonic tetanic contractions. Hudgins and Stetson, **290**; Travis, **251**. The extent of the pitch variation is probably conditioned by the power of the ear to distinguish small increments of frequency. Obviously, a variation of

more than a semitone in all might give an auditory impression of false pitch.

§ 25·22. **The Vibrato.** It is most probable that the vibrato is effected in physiological terms by a semi-tetanic stimulation of the extrinsic laryngeal muscles producing a periodic modulation of the vocal cord vibratory motion and hence varying the sound pitch. Westerman, **394**. Most pitch vibratos are accompanied by an intensity vibrato of the same rate. It is probable that the intensity vibrato is produced by a periodic narrowing and opening of the laryngeal aditus, effected by action of the cricoarytenoid lateralis, cricothyroid and lower pharynx constrictor muscles. Close study of motion pictures of famous singers, especially those of less-trained singers, show for the vibrato an occasional movement up and down of the tongue in synchronism with the vibrato rate, and this movement will often extend to the lower jaw and the lips. If these tongue and jaw movements are considered independently from the probable concomitant laryngeal movements, they could affect only the intensity of voice. It is most probable that they are accessory to the accommodation that is taking place in the larynx to produce the frequency vibrato. The fact that these accessory tongue, jaw and lip movements occur most often in relatively untrained singers and are more inhibited in trained singers indicates that there is probably an overflow of muscle tonus from the larynx muscles to the lingual and mandibular muscles. The intensity vibrato has little reaction upon the frequency rate. The frequency vibrato is most probably produced by direct action of the extrinsic larynx muscles upon the action of the vocal cords and may depend upon the antagonism of the posterior cricoarytenoid and the thyro-arytenoid muscles which assure the vocal cord tension. In other types of muscle action a rhythmic relaxation and tension of antagonistic muscles is less tiring than a continual state of tension. In the vibrato laryngoscopic observation does not show much degree of pharynx constriction and tension. Conversely, in the tremolo the pharynx is usually

contracted and tensed. This is often a cause of throatiness of voice. In the vibrato the globules of mucus which thickly coat the walls of the pharynx and larynx and vocal cords may be seen to vibrate at the same rate. Stanley and Maxfield, **244**, p. 102 ; Weiss, O., **387**, p. 1371.

§ 25·3. **The Trill.** The trill is virtually an accelerated form of the vibrato. The rate is increased up to about 10 to 12 per second and is apparently fixed for each singer. Stanley and Maxfield, **244**, p. 110. There is not as much information available about the trill as about the vibrato, which has been extensively studied. Seashore, C. E., **243**. The use of the trill is limited to a few passages in the higher registers, while the vibrato is present in nearly all sung tones, especially in good voices. The trill is more exaggerated than the vibrato and is perceived by those who may not hear the vibrato. The intensity and pitch ranges are more extensive, probably because the trill is used on high pitches by soprano voices. The nature of the trill is a rapid, equal and distinct production of two tones separated by an interval of a major or minor third. Garcia, **228**. These tones are an upper, accented tone and a lower unaccented tone. The trill is characterized by the steadiness of the rate of alternation and the clear differentiation of the two tones. Nadoleczny, **316**, p. 1.

§ 25·4. **The Tremolo.** The tremolo is a type of vibrato consisting more of an intensity than frequency modulation, occurring at about the same rate but over a wider range and with greater variability and with lack of control. It is more prominent than the vibrato and is used, therefore, for the effect of pathos and in a deliberate sequence of increasing and diminishing prominence. It may be the result of a periodic shutting off and on of voice by means of abdominal and thoracic spasms of respiration at a minimal rate, 5 to 6 per second, which tends to smooth out the auditory effect of the cessations of voice into that of a pulsating sound change. In this way the frequency of the tremolo may be studied from the records of the respiratory spasms. Flatau,

225; Nadoleczny, 317. It is apparently characteristic of a throaty singer, and in this case may be produced by a progressively increasing tension in the pharynx constrictor muscles, which sets up a tetanic fluttering of the epiglottis, tongue and even the lower jaw. Stanley and Maxfield, 244, pp. 102, 150. The attempt to pass from the tremolo to the vibrato usually results in an unpleasant intensity wobble. A type of pulsating tremolo is associated with the heart sounds in the aorta and bronchi. In this case the rate is synchronized with the rate of heart beats. Weiss, O., 387, p. 1370.

§ 25·5. **The Falsetto.** The use of the falsetto voice is dependent largely upon singing training and the traditions of the society. It is used as a means of reaching pitches above the normal compass. Many countries have established traditions of voice quality. Thus Caucasian, Arab and Armenian folk songs are sung with a nasal, falsetto voice. The Nordic races have a more guttural emission, while the Latin races have a clearer emission, due to the predominantly labial pronunciation. Tarneaud, 245, p. 16. Tropical races favour a predominantly nasal quality. Duverger, 275. In European song traditions the falsetto used to be much more common than it is now, just as the occurrence of many alto voices, produced by arrested sexual development in the male, is much less common now than in the eighteenth century. For the specific effect known as the yodel, the mechanism of passing rapidly and alternately from normal to falsetto voices, on the same pitch or over a short interval, is definitely established as a singing practice. In addition, the bleat, that is the alternation up and down of pitch, probably produced by tension and relaxation of the posterior cricoarytenoid muscle, is used occasionally for a specific effect only. Negus, 238, p. 430.

§ 25·6. **Nasality.** The use of nasality in singing is subject to a great deal of argument. It must be remembered that the major control on the quality of a singer's voice is the auditory percept formed by the ear. Accordingly, in a

language community which is already prone to nasalize speech, a nasality of singing may pass quite unnoticed, while it would be noticeable and probably distasteful to a member of a language community not having nasal speech. Moreover, the fact of the opening of the nasopharynx does not necessarily produce a nasal quality of sound. Russell, **242**, p. 18. Certain so-called nasal 'twang' in varieties of American speech is caused by a pharyngeal constriction at the region of the epiglottis. Russell, *op. cit.*, p. 42. This constriction serves to add to the larynx sound certain component tones, mainly in the frequency region 300 to 600 cycles, and these added components form the so-called nasal quality. A minimal opening of *circa* 25 sq. mm. is necessary for the nasopharynx to have any reaction upon the sound quality. Rousselot, **117**, 1, p. 268. The analysis of the waveforms for nasal sounds shows that strong components in the region 300 to 600 cycles characterize these sounds. Accordingly, if the fundamental voice pitch comes near this frequency region, the opening of the nasopharynx will reinforce the fundamental intensity and produce increased loudness rather than a nasal quality. Thus a baritone or tenor singing in the upper part of the compass might use an open nasopharynx to reinforce the loudness of the voice. Conversely, if the fundamental pitch were outside the limits of this frequency region, the use of the nasopharynx would tend to reinforce the harmonics of the voice sound that resonated with the cavity frequency and so produce the characteristic quality change known as nasality of voice. The use of the nasopharynx on the upper register is rare and not desirable. A nasal quality occurring in a soprano or contralto voice is usually confined to the lower part of the compass. Rabotnow, **329**. Incidentally, the author has found in studies of the use of the nasopharynx in singing, that a contralto may sing over the lower range of the compass with the nasopharynx open and then shut it off at a definite pitch, usually near the transition, and continue up without use of the nasopharynx.

§ 25·7. It must be emphasized that the action of the

accessory nasal sinuses : the frontal, sphenoidal and maxillary —is at most to absorb energy from the larynx sound. The original purpose of these paranasal sinuses was that of extended olfactory mucous membrane from the nose, but that purpose is no longer subserved. Negus, **238**, p. 96. By reason of the tiny ostia of the sinuses into the nasopharynx and the fact that they are entirely enclosed in the skull structure, they cannot act as resonators to increase or modify the larynx sound. The sinuses may be filled with fluid or obliterated and incorporated into the nasopharynx by surgery without thereby any direct effect on the larynx sound. Any vocal changes consequent upon surgery of this region are the result from attendant disturbances of other parts of the speech system. Inflammation of these sinuses affects the sensory endings in the nasopharynx from the sympathetic and trigeminal nerves, which thereby react upon the phonatory action of the voice. Tarneaud, **364**. It is reported that Caruso was able to produce audible sound by tapping the mastoid bone with a finger, and he claimed, and others claim, to possess in this way absolute standards of pitch. Paget, **160**. The 'masque,' that is, the skull and the skull cavities other than those of the speech system, acts rather to absorb sound than to radiate it. Husson and Tarneaud, **291**, p. 979. The thorax may absorb energy from the larynx, particularly when the vocal cartilages are low in the neck and the consequent selective transmission of energy to the thorax has led to the popular use of the term 'chest voice' for the lower pitch range. Conversely, on the upper pitch range the larynx is raised in the neck and the energy tends to be transmitted selectively to the skull, producing the sensation of 'head voice.' The use of these terms has led to many false suppositions of the origin of voice in these regions.

Singing

§ 26·1. For the details of singing technique as shown in performance, we are greatly indebted to the recent work by the University of Iowa (Dean C. E. Seashore). It is impossible

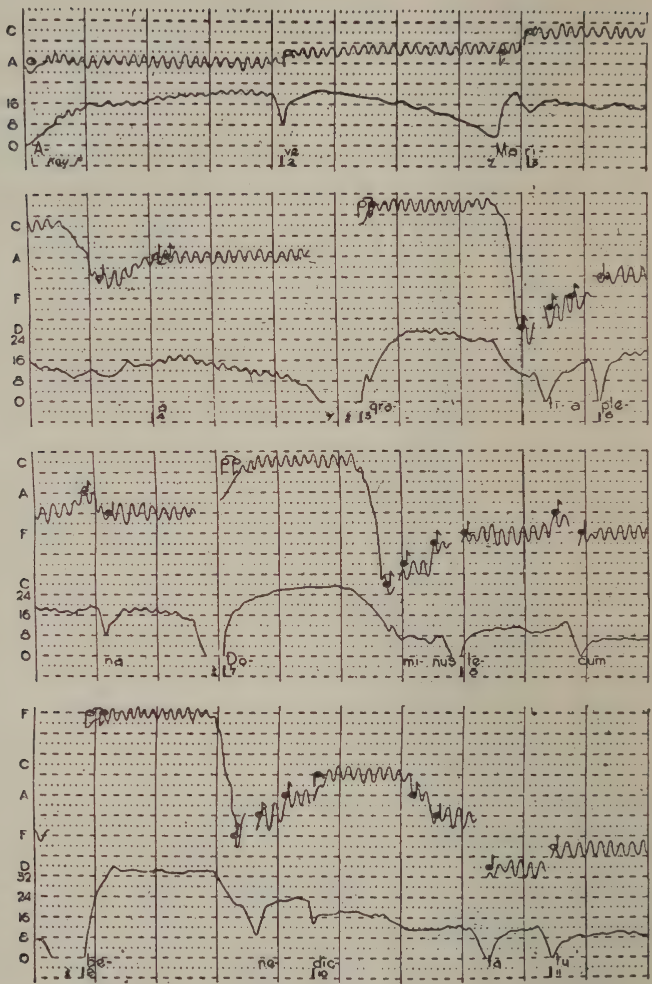

FIG. 17. Records of the singing voice. (*Courtesy of the University of Iowa.*) The upper horizontal line represents the pitch of the voice. The lower line indicates the intensity of the voice. The solid vertical lines indicate time in seconds. Within these limits the dots and dashes indicate tenths of seconds. The phrasing and measures are indicated at the base of each strip.

here to do more than summarize the valuable information collected. Of the factors of sound those of pitch, intensity and duration are of major importance in this study. The factor of quality is largely dependent upon the two associated factors of pitch and intensity. High pitches are necessarily sung with a changed quality from that of low pitches; intense voice likewise produces a quality change. *Vide* Chapter III. The factor of pitch is most important to the melody and hence the framework of the song. The transfers between different tones are carried out by continuous voice in the form of portamentos or glides, or by the release of one tone and the attack of the next tone after a pause. In performance many portamentos are added by singers in cases when a voiced consonant at the transfer point must be vocalized to permit the transfer being carried out. 'Iowa Studies in Psychology of Music,' **102**, 4, p. 74. The vibrato, which persists in nearly 90 per cent. of singing, is carried through a transfer in the portamento. Certain authors consider that the vibrato is an essential means of producing the portamento. Stanley and Maxfield, **244**, p. 108. Apparently some 40 per cent. of all transfers are portamentos. In the attack of a tone the peaks of pitch and intensity are reached by a process of exponential acceleration from silence. The most agreeable attack is produced by a smooth, rapid rise of pitch and intensity accomplished usually in 2/10ths second, and over a pitch extent of about 8/10ths of a musical step. 'Iowa St.,' p. 170. Obviously, the longer the duration of this acceleratory attack the more obvious will be the auditory effect of slurring and prolongation. Since the physiological action of the attack involves co-ordination of muscle action in thorax, larynx and pharynx, there is a minimum time interval in which these actions can be increased to a maximum without undue strain or disco-ordination. If the expiratory period begins with the vocal cords pressed together, the attack is abrupt and strained, producing a harsh quality or even beginning with a glottal stop. The release should likewise consist of a smooth deceleration of pitch and

intensity fall, involving relaxation of tension in a gradual fashion.

§ 26·2. **Intensity.** The intensity factor in singing gives greater scope to the artistry of the performer. The singer is able to interpret the song as he wishes, subject only to the reference scale of intensity change established by the composer. Accordingly, in those languages in which metre is dependent upon stress patterns, certain intensity patterns found in speech are also most common in singing. In phrasing in European songs, the most common intensity pattern is that of a considerable crescendo followed by a considerable decrescendo (*op. cit.*, p. 91ff). Such a type is the pattern of a normal phrase spoken without emphasis upon any syllable. The next most common pattern is that of a short crescendo followed by a long decrescendo. This has a pattern similar to the stress pattern of the English sentence : 'Despite what you say, I don't believe it.' The third type is that of a long crescendo to a climax often without noticeable decrescendo and terminating in a release. This is similar to the stress pattern of the English sentence : 'Is he going to do it now ?' Obviously, moreover, in languages in which much of the emotional content of speech is conveyed by stress (that is, intensity) patterns the typical patterns for various emotional states are relatively fixed and equally applicable to speech and song. For that reason, to a European audience Oriental music and song may appear quite inexplicable in point of intensity and pitch patterns.

§ 26·3. **Duration.** The durational factor in singing is equally variable and conditioned by the artistic conception formed by the singer. The conventional indications of tempo are only vague terms—adagio, largo, andante, etc. In performance these terms acquire meaning only in connection with the expression of the song. Apparently, the principle of a retard towards the end of the song in legato style is the most characteristically stable form of durational artistry. 'Iowa St.,' 4, p. 105. The importance of this factor lies in its use as a means of indicating termination and

giving a sense of completion in similar fashion to the finale in orchestral music. In legato singing the time given to pauses for transitions, phrasing or inspiration is about 10 per cent. in all. In the pattern of over- and under-holding of tones in variance from the durations indicated by the score, great variability is found. 'Iowa St.,' 4, p. 110. There is a certain tendency for short notes to be over-held, and for long notes to be under-held, the latter especially when they occur on closed syllables before a consonant or consonant group. There is a typical rise of duration in the last third of the song, and when there are interludes in the song, the singer tends to use minor retards just before the intervals. There are typical variations of about 10 per cent. in duration of successive measures, but the overall durations of the same song sung by different singers agree quite closely.

Training

§ 27·1. In discussions upon the training of singers a great deal of very vague theory has been put forward in the guise of scientific fact. It is not always a correct assumption that a good singer is *ipso facto* a good teacher of singing. Drew, **274**, p. 125. There is a certain tendency for a given singing style to be forced upon all pupils irrespective of the difference in anatomy, vocal power and temperament between pupils. Certain fundamental principles of training are often overlooked in favour of a quasi-scientific discourse about voice-placement or 'resonance,' that conveys very little to the reader. Cæsari, **219**. Fundamentally, voice training is also ear training, since the auditory control of voice is very important. Provided the limitations of the ear are assisted by instrumental means of study, ear training should involve not merely the recognition of the performance characteristics of other singers and instruments but also the careful description of these factors. The compass of the voice should be carefully determined by tests as well as by the available instrumental means of study, such as the stroboscope and the larynx measurer. All extremes of pitch and intensity should

be avoided in the early training until the adequate control of accuracy has been achieved. Exercises should be sung always on a vowel which can be accommodated to the pitch of the voice. If a consonant is added, it should be a voiced continuant consonant like [l]. The teacher must be expected to have sound understanding of the available studies of vocal anatomy and physiology, and must be on the alert for signs of physical strain and ill-health in the pupils.

§ 27·2. **Disorders.** Singers are liable to certain disorders of the vocal system resulting frequently from over-exertion, singing above the compass or in a style for which they are not equipped. The instrumental means for studying the vocal action should be available and should be used by a properly instructed person. Closer co-operation than at present between laryngologist, phonetician, singing teacher and speech therapist is definitely desirable for the benefit of all those interested in the subject of the human voice. Much of the recurrent laryngitis of singers may be traced to the attempt to sing above the normal compass or outside the average intensity range. The vocal cord length is a definite factor in the determination of compass; thus, soprano voices have cords some 14 mm. long; contraltos, 18 mm.; tenors, 22 mm.; and basses, 25 mm. Zimmermann, **398**, p. 130. The dimensions of thorax and abdomen are not so significant. Good singing does not depend upon a powerful expiration with excessive amount of air but on the co-ordination of the respiratory and laryngeal mechanisms. Intensity of voice should be subordinated to the accuracy of pitch and quality. The average lung capacity (3 to 4 litres) is ample for the production of powerful voice over the longest musical phrase, lasting some 16 seconds. Excessive expiration results in vocal cord dysfunctions. The relative elevation or depression of the larynx in the neck is not so intrinsically important as the production of good voice quality. The displacement of the larynx is a consequence of the action of the extrinsic laryngeal muscles for the higher pitches, and, if the requisite pitch can be obtained with good quality without noticeable

displacement of the larynx vertically, such an action is quite normal. Damage may result, however, from faulty phonation with a larynx excessively high or low in the neck, and in this case the action should be corrected.

§ 27·3. Occasionally, singers who are prone to over-intense phonation are liable to produce a real damage to the tissue of the vocal cord. The repeated striking together in a forcible manner of the edges of the cords may produce a submucous hæmorrhage at the region of the stratified, squamous epithelial covering of the cords. Tarneaud, **246.** The area becomes degraded and increased layers of epithelium are built up until a definite, localized ‘ nodule ’ is formed on the vocal cord. This invariably occurs at the same place, roughly two-thirds along the cord from the posterior end at the arytenoids. In this case the prescription is rest and the patient must be referred to the laryngologist for the functional examination. The vocal cord action should be observed with the stroboscope so that the mode of vibration for the different pitches of the compass may be determined.

§ 27·4. The stroboscopic study of the vocal cord action has revealed certain interesting facts. It appears that quite frequently the action of the left vocal cord is abnormal. In these cases the left cord either fails to vibrate at all or vibrates with reduced amplitude as compared with that of the right cord. Tarneaud, **363** ; Nadoleczny, **318** ; Maljutin, **310.** In other cases the left cord may be fixed in the midline position so that the right cord beats against it. Or otherwise, the left cord may fix in the cadaveric, or half-open position, and the right cord crosses the midline to beat against it. The occurrence of these pareses or paralyses of the right cord is rarer. Maljutin, **310.** This disorder of the left cord may be associated with the incidence of left-handedness in certain people and the etiology of stuttering. Travis, **251.** Anatomical studies show that the course of the left recurrent laryngeal nerve is often longer than that of the right and, moreover, it is more liable to damage or local pressure from aneurysms of the aorta, œsophageal cancer or glandular

secretions. Burger, **263.** It is noteworthy also that otosclerosis generally begins in the left ear, while 'roaring' in horses is invariably due to paralysis of the left cord, usually by influenza or 'strangles.' Tilley, **374.**

§ 27·5. In conclusion, it must be emphasized that, while the scientific study of singing is just beginning, much of the available printed material on the subject is liable to confusion and misunderstanding. A great deal of this confusion centres round the misuse of the term 'resonance,' which may apparently cover up any deficiencies in scientific accuracy. Drew, **274,** p. 125. Co-operation in study between all the experts in the various lines related to the general study of voice is the best way to the reliable investigation of this most absorbing subject.

CHAPTER VII

VOICE AND HEARING

§ 28·1. While the major interest of this study is centred on the function of the voice, the allied function of hearing cannot be neglected. Accordingly, it is the intention in this discussion to give a brief outline of the anatomy and physiology of hearing and the more important relationships to voice in the auditory control and perception of speech and song. The sequence of the discussion follows the general lines of—firstly, the anatomy of the ear; then the physiology of hearing; thirdly, the exteroceptive control of voice; and, finally, the disorder of deafness. In the anatomical consideration the ear may be divided into three parts: the outer ear, the middle ear and the inner ear. These divisions are naturally interdependent, but exist to separate the outside air from the inner mechanism of perception. The outer ear is open to the air, but closed off from the middle ear by the tympanic membrane. The inner ear is closed off from the middle ear and communication is possible only through the oval and the round windows of the cochlea. The middle ear exists as a coupling mechanism between the external air and the fluid which fills the cochlear part of the inner ear. It also serves as a possible 'shock-absorber' to guard against the dangerous effects of excessively strong air vibrations or movements and possesses a relief valve, allowing excess air pressure to escape *viâ* the Eustachian tube. Hallpike, **57**.

§ 28·2. **The outer ear** is composed of two main structures: the pinna and the meatus. The meatus is the tube leading to the middle ear and closed at the tympanic membrane. The pinna, which originally served to close the meatus from outside air, consists of several continuous lobes, which possess some

nine vestigial muscles designed to allow of the folding forward of the pinna and the covering of the meatus. This action, which is frequently observed in animals, is absent in man. The meatus is a tube about 2·6 cm. long, partly cartilaginous and partly bony, which leads to the middle ear by penetrating the temporal bone. It is protected by outpointing hairs and a waxy secretion. It terminates in the tympanic membrane, which is a slightly concave, almost circular, thin diaphragm having three layers : the outer skin, middle fibrous network and inner mucous membrane. It is almost the same size in children and adults, has an area of about 0·6 sq. cm. and a thickness of 0·1 mm. The layer of fibres arranged radially and circularly renders the membrane virtually aperiodic. It is placed almost horizontally in the infant and obliquely in the adult, and is internally joined on the inner surface along a narrow area from the upper edge to the centre, or 'umbo,' to the handle of the malleus bone of the middle ear.

§ 28·3. **The middle ear** consists of a bony cavity called the tympanum or tympanic cavity, communicating *viâ* the long Eustachian tube to the rear of the nasopharynx, and adjoining the mastoid air cells. It contains a chain of three ossicles, or small bones, which link the tympanic membrane of the outer ear to the oval window of the cochlea. The middle ear communicates with the outer ear only by the tympanic membrane and with the inner ear only by the oval and round windows of the cochlea. The ossicles consist firstly, of the malleus, a hammer-shaped bone, some 8 mm. long, formed of a head, neck and handle, the latter being embedded in the tympanic membrane. The minute tensor tympani muscle runs from the wall of the cavity to be inserted into the head of the malleus. It is innervated by the trigeminal nerve and serves as an absorber of violent movements of the tympanic membrane by contracting and holding the malleus more rigidly. The malleus is articulated by the head to the incus, which is the second of the ossicles and is shaped like a miniature molar tooth, having a long process articulated to the head of the third ossicle—the stapes. This stirrup-shaped

bone is articulated at the head to the incus, and the footplate nearly fills the aperture of the oval window of the cochlea, to which it is attached by a ligament. There is a small stapedius muscle, which runs from the cavity wall to the head of the stapes, and is supplied by a branch of the facial nerve. In conjunction with the tensor tympani muscle it serves to reduce the transmission of vibrations to the cochlea, and hence to protect the inner ear from damage. The oval window of the cochlea is the stapes-filled aperture, about 3 mm. by 1·5 mm., which communicates with the scala vestibuli of the cochlea. The round window is a similar structure, about 3 mm. diameter, which communicates with the scala tympani of the cochlea. The Eustachian tube, some 37 mm. long, leads to the posterior nasopharynx near the adenoidal area. It is a means of drainage from the middle ear, but may often transmit infection from the nasopharynx.

§ 28·4. **The inner ear** consists of a very complex structure, having two parts: firstly, the semicircular canals, with the utricle and the saccule; and secondly, the cochlea. The canals, utricle and saccule are the organs of equilibration, and are connected with the vestibular fibres of the auditory nerve. The cochlea is concerned with the function of hearing, and is innervated by the cochlear branch of the auditory nerve. The function of the vestibular apparatus is dependent upon the motion of fluid: perilymph—in the three canals, which are disposed in the three cardinal planes of the body—sagittal, frontal and transverse. In the saccule and the utricle and the ampullæ of the canals the nerves terminate in hair cells, from which hair fibres penetrate up into a remarkable membrane in which are embedded numerous small masses of calcium carbonate, called otoliths. These otoliths load the hair fibres, and hence transmit to the nerves the movements of the fluid resultant upon changes in posture. The cochlea is a spiral structure, of two and three-quarter turns in man, and forming, if rolled out, a tube some 31 mm. long by an average internal diameter of 1·5 mm. This spiral form has been developed to avoid the auditory effects of

fluid motion consequent upon changes in posture of the body. It is filled with liquid and subdivided lengthwise into three compartments, by means of the osseus spiral lamina or shelf on the inside wall and two membranes—the basilar membrane and Reissner's membrane. The basilar membrane joins horizontally from the spiral lamina to the opposite wall of the cochlear tube. Reissner's membrane connects the upper surface of the spiral lamina obliquely and upwards to the opposite wall. The compartment below the basilar membrane is the scala tympani; this contains perilymph and connects by the round window to the middle ear. The compartment between the basilar membrane and Reissner's membrane is the ductus cochlearis, which is triangular in section, filled with endolymph and contains the organ of Corti. The compartment above Reissner's membrane is the scala vestibuli, containing perilymph and communicating with the middle ear by the oval window. The scala vestibuli and the scala tympani communicate through a small aperture—the helicotrema—at the apex of the spiral, but the ductus cochlearis is completely sealed off save for a tiny canal to the saccule.

§ 28·5. **The ductus cochlearis** is the main area concerned in the function of hearing, since it contains the organ of Corti, which is responsible for the transmission of the original sound waves as nerve impulses to the cortex. It is bounded above by Reissner's membrane, which is about 0·003 mm. thick, and hence readily transmits pressure changes in the liquid of the scala vestibuli. It is bounded below by the basilar membrane, a relatively thick structure, which supports the organ of Corti on the upper surface. The basilar membrane is supported by transverse fibres stretching from the outer rods of Corti to the spiral ligament which holds the membrane in tension to the wall of the cochlear duct. There are some 20,000 of these fibres, which increase progressively in length from 0·15 mm. at the base to 0·5 mm. at the apex, in step with a corresponding increase in the breadth of the basilar membrane. Conversely, the spiral

ligament, which tenses the fibres, decreases progressively in bulk and strength from the base to the apex. It is thus probable that the basilar fibres are differentiated progressively for both length and tension. The organ of Corti is a structure supported by a series of transverse epithelial arches formed by the growing together of stiff fibres arising from the basilar membrane. These arches support a large number of hair cells in two sets, consisting of: firstly, a single row of inner cells posterior to the arches; and secondly, several rows of outer hair cells anterior to the arches. The inner hair cells, totalling some 3,500, are disposed as two cells to three arches, while the outer hair cells, totalling some 18,000, are arranged in three or four rows. From the outer surfaces of the hair cells there project some twenty-five hairs to each cell, the upper tips of which may penetrate into the under surface of the tectorial membrane. This is a gelatinous membrane of fine, resistant fibres stretching transversely from the upper edge of the extension of the spiral lamina above the organ of Corti to the last outer row of hair cells. Like the basilar membrane it increases progressively in width from the base to the apex of the cochlea.

§ 28·6. **The innervation of the ear** and the cortical functional localization of hearing are fairly well known. The eighth or auditory nerve subserves the function of equilibration and the function of hearing. The vestibular division arises in three branches from the utricle, from the ampullæ of the superior canal, and from the ampullæ of the exterior canal. The cochlear division is formed of three branches, two of which, from the saccule and from the posterior ampullæ, probably constitute vestibular fibres incorporated into the cochlear division, while the third contains the cochlear fibres proper, and connects with the organ of Corti by some 4,000 apertures in the spiral lamina. The course of the vestibular nerve does not concern the present discussion, save that it may be noted that the vestibular fibres of both divisions terminate in a rather vaguely defined nucleus underlying the area acustica in the floor of the 4th ventricle, from which

some fibres arise to run to the optic thalamus. The course of the cochlear fibres begins at the dendritic axones of the spiral ganglia which ramify in the organ of Corti. From the spiral ganglia the axones penetrate the medulla to terminate near the ventral cochlear nucleus, near the inferior cerebellar peduncle, and the lateral cochlear nucleus, or tuberculum acusticum, in the floor of the 4th ventricle. Some fibres from the superior olivary nucleus pass to other motor nerves of eye and body, thus establishing reflex paths. In addition to the decussated fibres a small bundle arises on the same side to connect with the temporal lobe of the same side. But the auditory cortical area is connected chiefly with the cochlea of the opposite side. The lower trapezoidal fibres may be associated only with the vestibular section of the cochlear division, running from the saccule, and may terminate in the inferior colliculus. These fibres may be involved in sudden reflex actions incident upon loud noises, and it is noteworthy that they are more numerous in the lower animals than in man. Beatty, **38**, p. 152.

The Cortex

§ 28·7. The cortical functional localization of hearing is mainly centred in the temporal lobe. The auditory sensory area is mainly concealed in the Sylvian fissure, with a small part extending over the superior lip of the first temporal lobe. Stevens and Davis, **47**, p. 417. This is histologically an area rich in cells and fibres, with a well-defined band of fibres parallel to the surface, which show up in stained sections and are known as the lines of Kaes. Stevens, **47**, p. 418. The audito-psychic area is apparently located in the second and third temporal gyri. This area is characterized histologically by small cells and the absence of the lines of Kaes. In general there appears to be ground for supposition that the spiral organization of the organ of Corti is projected firstly, in the medullary cochlear nucleus, and thence *viâ* the medial geniculate body upon the cortical auditory area. Stevens and Davis, **47**, pp. 378, 418.

The Perception of Sound

§ 29·1. The mechanism of perception of sound is complex and variable by reason of the many powers of accommodation to stimuli possessed by the ear. External sound waves may reach the cochlea by three ways. These are: firstly, and most important, by the ossicular chain of the middle ear linking the tympanic membrane with the oval window; secondly, by air transmission across the middle ear from the tympanic membrane to the round window; and thirdly, by bone conduction directly through the skull to the cochlea. While an extensive perforation of the tympanic membrane causes only slight hearing loss, the adhesion or disruption of the ossicular chain may cause severe loss. In the absence of the tympanic membrane and the ossicles, the sound may be transmitted by air conduction to the round window and hence arrives in opposite phase to the normal sound transmission by the oval window. This can produce a phase difference between the sound falling on the normal ear and that perceived by the defective ear. Stevens and Davis, **47**, p. 254. The mechanics of the ossicular chain have been carefully studied, especially by a carefully constructed model. Stuhlman, **69**. The malleus and incus move as a single unit, rotating about the axis of the supporting malleus ligament, but the stapes does not move like a piston, but rather tilts about the axis of its lower attachment to the oval window. Two protective mechanisms guard the cochlea against the destructive effects of overload sound stimulation. Firstly, the stapedic movement changes under great intensity to a rocking action about the long axis of the footplate; and secondly, the tensor tympani and stapedium muscles may fix the tympanic membrane and the stapes, thereby reducing the transmission-factor of the ossicles by some 30 per cent. The natural period of the mechanism is at about 800 to 1,200 cycles, and the damping factor is at least 50 per cent. The basilar membrane is probably critically damped so that it is effectively a dead-beat vibrator. Stevens and Davis, **47**,

p. 263. The probable reduction of movement in the ossicles is about 2 : 1, in the coupling together of the two systems of different densities and hence impedances, viz.: the external air, and the cochlear fluid.

§ 29·2. **The Cochlea.** The mechanism of the cochlea is very complex and open to much discussion. It is impossible here to give any account of the variant theories of cochlear function, but rather it is the author's intention to avow his subscription to a particular theory—the 'travelling wave' theory. Stevens and Davis, **47**, p. 278. The bony labyrinth is a virtually sealed chamber with rigid walls save for the two windows. The lymph is practically incompressible, and hence the inward motion of the stapes must be accommodated for by the outward bulging of the round window. The necessary movement of lymph might take place *viâ* the helicotrema, but it is most probable that a displacement of the basilar membrane into the scala tympani causes the necessary pressure accommodations between the two scalæ. The more rapid the movement of the stapes, with higher frequencies of the sound, the closer the bulge of the basilar membrane comes to the round window. Stevens and Davis, **47**, p. 276. So the basilar membrane tends to vibrate selectively at a given part according to the frequency of the sound, the bulge being nearer to the base for high-pitched sounds and nearer to the apex for the low-pitched sounds. The movement of the basilar membrane may tend to produce eddies of lymph above the area of vibration, and these eddies may stimulate the nerves at these regions, thus producing the analysis of sound.

§ 29·3. The localization of frequency along the basilar membrane is well established by various means—notably, by the histological study of sections of human cochlear degenerations for various types of hearing losses, recorded before the death of the patient. Guild, **55**. The lowest frequency perceived is about 18 cycles, and the range extends to about 16,000 cycles, though few people can hear sounds as high as that, and many others are unable to hear sounds

above 12,000 cycles, much less distinguish pitch differences. The range decreases considerably with increasing age, notably in the upper frequency scale, so that at sixty years the threshold of hearing at 8,192 cycles may be some 23 decibels higher than that at twenty years. In the localization on the basilar membrane the lowest octaves are crowded together on the apical turn and at the helicotrema, while the upper octaves spread out progressively along to the base. This crowding at the apex probably explains the poor differential pitch sensitivity of the ear for low frequencies. In audiograms of relatively deaf persons, 'tonal islands,' or isolated frequencies or frequency regions to which the ear is insensitive, may be noted. These tonal islands are usually regions of relative rather than absolute deafness, since the intensity range of the audiometer may be inadequate to show up the presence of any hearing for these regions. These tonal islands may be associated with localized areas of degeneration or destruction of the organ of Corti. Guild, **56**.

Hearing

§ 30·11. Recent investigations are making more and more evident the complexity of the psychophysics of hearing. Fletcher, **53**, **54**. The five characteristics of a sound: frequency, intensity, quality, duration and phase—may be measured more or less accurately with the aid of scientific instruments. But the psychological auditory percepts of these factors constitute the identity of the sound as perceived by the hearer, and these percepts are relative, variable and inter-affective. Thus the psychological percept of pitch corresponds for a given hearer to a given frequency, but it is also dependent upon intensity, quality and duration. In the case of pure tones the pitch percept varies with the changes in intensity in the following manner. The variation is least at the region of maximum sensitivity of the ear: about 2,000 to 2,500 cycles. For tones up to 2,000 cycles the pitch decreases with increase in intensity; for tones above 2,000 cycles the pitch increases with increase in

intensity. Fortunately for our perception of ordinary sounds which are most often complex, this pitch variation with intensity is very slight for complex sounds. The interdependence of pitch and quality is shown by the fact that, even if the fundamental is filtered out of a complex sound, any three consecutive harmonics will combine to produce difference tones which reproduce the fundamental. Thus three even harmonics at 400, 600 and 800 cycles, reproduce a fundamental at 200 cycles. The addition of the harmonics at 500 and 700 cycles results in the audible drop of the fundamental to 100 cycles. The relationship of pitch to duration is complicated by the fact that, by the principle of uncertainty, the frequency spectrum of a tone depends upon its duration, so that a single pure tone of infinite duration contains a single frequency, while a similar tone of limited duration would have an extended frequency spectrum. As a tone is increased in duration from silence, the auditory percept changes from that of a toneless click to that of a click with some sense of pitch and finally has a definite pitch. The absolute time required for the establishment of tonal pitch is least (*circa* 0·01 second) in the middle region about 2,500 cycles, and increases above and below this region to *circa* 0·04 second at 100 cycles and 0·025 second at 10,000 cycles. These data, which are only approximate, would show that in speech, especially on high-pitched fundamentals, many very short sounds are not heard with very definite pitch. Thus quite often syllables may be assigned pitches corresponding only to the general levels or averages of the component fundamental frequencies of the speech sounds.

§ 30·12. In the singing of tones having a variable frequency, as in the vibrato, which recurs 6 to 7 times per second, the principal pitch equals roughly the geometric mean of the frequency range. Pitch glides are judged more extensive if their durations are longer. Lewis, **61**, p. 346ff. As might be expected, a scale of pitch units, established by the fractionation method, corresponds neither to the musical nor to the frequency scales. By this method, in which a

variable frequency is altered until its pitch sounds half of that of a fixed reference frequency, a provisional table of pitch units, called mels, has been established. This substantiates the fact that equal musical intervals in different parts of the scale do not constitute equal subjective intervals, but become subjectively larger as the frequency increases. Stevens and Davis, **47**, p. 84. The just noticeable difference in frequency, known as the difference-limen, is a measure of the resolving power of the ear. The difference-limen (DL) depends upon the frequency, intensity and rate of frequency change. The measurement is more frequently expressed as the ratio of the difference-limen to the frequency, and hence the relative difference-limen (Δ f/f). This is approximately constant at 0·0003 above 500 cycles. Below 500 cycles the relative difference-limen increases to 0·04 at 62 cycles. For a fixed intensity of 40db above threshold there are about 1,500 just noticeable steps in frequency over the audible range, giving a total of about 340,000 distinguishable tones. Stevens and Davis, **47**, p. 152.

§ 30·2. The intensity of sound denotes the magnitude of vibration in terms of pressure or energy as measured by instruments. Loudness is a psychological aspect of sound related to the auditory percept of intensity. The decibel is a stimulus-unit expressing the relation between two intensities and referring to an arbitrary zero level. This zero is established as a pressure of 0·0002 dynes per sq. cm., or an energy of 10^{-16} watts per sq. cm. Stevens and Davis, **47**, p. 110. The loudness level of a given tone is defined as the intensity level of a reference tone of 1,000 cycles which sounds equal in loudness to the given tone. Stevens and Davis, **47**, p. 111. The term ‘ sone ’ is used to indicate a unit of loudness level. These are not absolute scales but are relative only to an arbitrary zero. The loudness, as well as the quality of a tone, depends upon the duration. For durations up to 1 millisecond, the loudness increases with duration. For durations longer than 1 millisecond, the loudness is not affected but depends upon the intensity. Snow, **67**.

§ 30·3. Other tonal attributes include volume, density and brightness. Volume is the subjective aspect of a tone denoting an apparent largeness of extensiveness. Judgments of volume have been made by giving the observer alternate tones of different frequency and asking him to vary the intensity of one until it equalled the other in regard to volume. Stevens and Davis, **47**, p. 161. Apparently the volume of a tone increases with increase in intensity and decreases with increase in frequency. It is quite possible that there is some degree of empirical psychological correlation of this attribute with experience of loud, low-pitched tones coming from large objects, and *vice versâ.* Density is the subjective impression of the relative compactness or firmness of a tone. Apparently it increases with both frequency and intensity. The brightness (as contrasted to dullness) of a tone appears to be somewhat closely correlated with frequency, but is more probably dependent upon harmonic structure and loudness. Tones with a larger number of high-frequency harmonics are judged brighter than those with low harmonics. Moreover, the louder of two tones tends to be judged the brighter. It is possible that for pure tones brightness is identical with density, but for complex tones brightness is related to the harmonic structure.

§ 30·4. **Localization.** The faculty of the localization of the position of a sound source is an interesting phenomena. It is apparently based upon small differences in intensity and phase (including respective times of arrival) between the incidence of the sound waves at each of the two ears. Differences in intensity between the sounds led separately to each ear cause an apparent shift of the localization towards the side of the greater intensity. In the actual case of a source located to one side of the observer the difference in intensity at the two ears is a function of frequency and dependent upon the sound-shadow of the head. For low frequencies this effect is very small, but for frequencies above 5,000 cycles the difference may be as great as 30db. In a complex sound this produces an unequal perception of

high over low tones. Phase differences at the two ears tend to produce the effect of location towards the side receiving the leading phase. Stevens and Davis, 47, p. 171. If the phase difference passes 180 degrees, it becomes a durational difference which may increase up to 2 milliseconds before the sounds appear to be distinct and separate at each ear. Judgments of distance of a sound source are far from linear. They are presumably based upon differences in the general intensity as well as the changing relationships of phase and intensity at each ear consequent upon displacement of the sound source with relation to the hearer. It is likely that the judgment is conditioned by the Weber-Fechner principle.

§ 30·5. **Modulation.** In normal circumstances the sounds reaching the ear are most often complex and only rarely pure tones. These complex tones may often be modulated in some way, either in frequency, or in intensity, or both. An especial example of a tone modulated in frequency, and often also in intensity, is the sung tone having the vibrato. The vibrato occurs also in instrumental music in the violin, for which the physical action is essentially a rapid variation in the length of the vibrating string, accomplished by a quasi-tetanic movement of the finger on the stop. The vocal mechanism of the vibrato in singing has been discussed above. The average rate of the vibrato is about 6 to 7 per second, and the frequency modulation is about one semitone for the singing voice and one-quarter tone for the violin. The nature of this musical ornament depends apparently upon an interesting factor in hearing. If, in the periodic frequency modulation of a given tone, the rate of modulation is increased gradually from 1 per second, the perceptual effect is that of an increasing rapidity of the change up and down of pitch up to a rate at which the change in pitch vanishes, giving place to an apparent periodic intensity change. At the same time the apparent richness or complexity of the tone increases to a maximum at about the same rate, which is at 6 to 7 per second. Stevens and Davis, 47, p. 235. The physical stimulus of a pure tone modulated, for example, at a rate of 2 per second,

is that of a complex tone containing many individual components spaced 2 cycles apart and reacting on the basilar membrane in such a way as to cause the maximum point of disturbance of the membrane to move back and forward. When the rate reaches 7 per second, no matter how extensive the excursion of this maximum point, the gliding character is lost. Stevens and Davis, **47**, p. 238. In such studies as have been made of this section, the range of frequency, in the modulation at 7 per second, varied from 18 cycles at 500 cycles to 26 cycles at 3,000 cycles fundamental. To the musician the vibrato is a means of covering small fluctuations in the accuracy of frequency production. The perceived principal pitch equals roughly the geometric mean of the frequency modulation. In glides, which partake of the nature of slow frequency modulations, the perceived pitch depends upon the extent and duration of the glide. Short, rapid glides may give rise to the percept neither of a single definite pitch nor a pitch movement. Lewis, **61**.

§ 30·6. **Masking.** Under certain conditions the response of the ear to a normally effective auditory stimulus may be reduced or absent. In one condition, the stimulus may be accompanied by another sound which masks or obliterates it. One tone is said to be a masking tone when it acts to raise the auditory threshold for the second tone. Stevens and Davis, **47**, p. 209. Apparently for pure tones the masking effects vary with the frequency and intensity relationships of the two tones. As far as concerns voice, it is evident that the intensity of phonation requisite to be heard above a noise will depend upon the intensity of the masking noise. The overloud orchestra, which is a frequent accompaniment to much modern concert singing, is often a real handicap to the singer, who is obliged to overstrain the voice in the attempt to rise above the masking sounds.

§ 30·7. **Fatigue.** The second condition is that of the abnormal, fatigued state of the ear. In this case, the threshold may be displaced in varying degree. Again fatigue is greatest at the frequency of the fatiguing tone, and there seems to be

evidence for the supposition that fatigue is a central rather than a peripheral phenomena. Certainly the voluntary deafness or oblivion to noise, which is practised by all travellers in the underground railways, appears to be of central origin, since it varies according to the degree of attention paid to the noise. Obviously, too, the singer, who is required to perform in a noisy hall, cannot have so accurate a control of the frequency and intensity of phonation as he would have in quiet surroundings. The mutual obligations of singer and audience are strongly evident in the consideration of the question of fatiguing, masking noise.

The Auditory Control of Voice

§ 31·1. The exteroceptive control of voice by the function of hearing is obviously very greatly affected by the factors which have been outlined above. In the normal hearing individual this control of voice is probably made much more important than the combined value of visual, tactual and kinæsthetic controls. In the partially and the wholly deaf persons the exteroceptive control is impaired or lacking and may be implemented or replaced by the use of hearing aids or the cultivation of the visual sense. The methods employed in these ways of assisting deafness will be discussed below, but there is space here to consider the operation of the normal exteroceptive control on speech and singing. In speech the importance of accurate perception of quality is obviously very great for the adequate comprehension of other speakers. Among the various speech sounds the sequence of diminishing auditory recognizability comprises firstly, the back vowels, then the diphthongs and triphthongs, the front vowels, the voiceless consonants, the nasals, the voiced continuant consonants, the voiceless stop consonants, and finally the voiceless consonants. Fletcher, **40**, p. 73. The more hurried and clipped the speech the greater the tendency for the less-recognizable sounds, especially the voiceless consonants, to be confused or lost. In some cases the perception of the visible articulatory movements for certain of the less audibly

recognizable sounds, such as [f, θ], will assist in the comprehension, and in these cases the speaker's face and neck should be clearly visible. In singing, in which the less recognizable voiceless sounds tend to become voiced (and hence recognizable) or are lost, the exteroceptive control is more concerned with production of good singing quality. Provided the singer's auditory perception is not masked or fatigued by extraneous noise, the exteroceptive control will depend upon the nature of the singer's ear and the degree of training of that organ. For this reason, it is probably true that voice-training involves some degree of ear-training.

§ 31·2. **Pitch.** The exteroceptive control of frequency and pitch is rather variable in individuals. Some people possess no ear for pitch; that is, they lack the capacity to refer a given frequency to some acquired pitch standard and scale. Bachem, **49**. Such people inevitably sing off pitch and speak without great regularity of intonation, often tending to reduce the range of pitch changes. The control of intonation for any given spoken language seems to become almost a reflex action, in a semi-automatic fashion, which may perhaps be integrated at the level of the cerebellum rather than at the cortical centres. In learning a foreign language, the intonation of the native language is longest maintained and that of the foreign language slowest acquired of any of the characteristics of spoken languages.

§ 31·3. **Rapidity.** The exteroceptive control of duration and rapidity of speech is probably not especially significant. A rapid speech is symptomatic of the pressure of thoughts, but not especially phonemic in value. In singing, however, the control of duration, and hence of rhythm, is of great importance, and good singers come to possess quasi-absolute standards of tempo and duration. This is probably partly concerned with the auditory perception of duration, but dependent rather upon various types of physiological tempo such as the muscular reaction-times in tongue tapping, finger movements and the like. Moreover, the apparent duration of a sound is greatly conditioned by intensity. A sound of

given intensity and duration will produce a perceptual apparent duration equal to that of a sound twice as intense and lasting half as long. Lifshitz, **62**, p. 231.

Impaired Hearing

§ 32·1. Impaired hearing may be of three main types. In the first case, the main factor is a failure of the transmission of the sound waves to the cochlea. This is frequently described as transmission deafness, and is usually dependent upon some defect or pathology of the tympanic membrane and the middle ear. This may occur as a congenital state of the absence of ossicles or the tympanic membrane or a diseased condition of the middle ear bringing adhesions or degenerations of the ossicular chain. The meatus also may be occluded by incrustations of wax or accumulation of secretions around foreign bodies. The tympanic membrane is often pierced by the action of inflammation of the middle ear, though perforation of the membrane *per se* does not always produce deafness. Fixations of the footplate of the stapes in the oval window may occur through the little-understood onset of otosclerosis, which produces increasing deafness throughout the whole frequency range. Otosclerosis is apparently associated with a progressive degeneration of the hair cells in the organ of Corti.

§ 32·2. The second factor in the production of impaired hearing is the damage to the sensory cells or the nerve fibres and centres. This may be of the form of degeneration in the nerve trunk of the auditory nerve or in the hair cells of the organ of Corti, and is usually called nerve-deafness. Damage to the nerve trunk may occur by local lesions, or, more especially, by surgical damage and the results of local inflammations of organs. Hamblen-Thomas, **70**. The localized damage to the organ of Corti may be congenital, as in the form of insufficiency of nerve-elements of hair cells or direct destruction of the organ after loud stimulation. The occurrence of tonal islands of deafness is probably associated with localized defects of the organ of Corti, which are, of

course, equivalent to damage of the associated nerve fibres.

§ 32·3. The third type of impaired hearing is concerned with the dysfunctions of the higher nerve centres, whereby the nerve impulses from the cochlea reach the auditory centres but the subject is unable to perceive sound or give meanings to the received sounds. Schindler, **66**. This is the type of the so-called central deafness and may involve lesions at various levels of the central nervous system, especially congenital or birth injuries of the cortical centres of audition. This is a form of auditory aphasia in which the actual perception of the received sound impulses is impaired.

§ 32·4. In cases in which the pathway for air conduction of sound is impaired the path of bone conduction may become very important. In human beings an especial pathway for bone conduction of sound to the lymph of the cochlea is the bony trabeculæ of the subaditus region. Fracture of these trabeculæ affects the bone conduction much more radically than anything else. Stevens and Davis, **47**, p. 295. The normal pathway in testing the bone conduction power of the ear is by the mastoid process. Naturally in cases of middle ear conduction deafness the value of bone conduction methods is very considerable, and the difficulties of constructing types of bone conduction receivers with highly variable characteristics are the main impedances to the greatly extended use of this method of remedy. Kerridge, **60, 61**. Other possible means of assisting the function of hearing consist of the substitution of visual observation of the articulatory actions of the speaker. This consists of observing the surface movements of the face, the movements of the tongue, lips, lower jaw, and the elevation and advancement of the larynx in the neck, especially the thyroid notch. This method may be best termed Visual Hearing. Mason, **64, 65**. Another method of educating speech in the deaf child is to stimulate the kinæsthetic control by the practice of guiding the speech organs into the requisite positions for the sounds. Stinchfield and Young, **177**. This requires great manipulatory skill on the part of the teacher, since the various

actions for the speech sounds should be performed at normal rate. The various forms of modern electrical hearing aids are as yet far from perfect, especially in the matter of adjustment of the frequency response to suit different types of hearing losses. Obviously the best method is a combination of the aid, if there is enough residual hearing, with the method of visual hearing.

Deafness and Speech

§ 32·5. The speech of persons in various stages of deafness is naturally variable. The speech of an adult suffering from only a slight hearing loss is usually normal, though the intensity tends to be increased. The natural habits of speech are already fixed before the onset of deafness, and they do not change greatly. His difficulty is naturally with the perception of the speech of others. Lindner, **63**. Accordingly, the subject matter and the relevancy of the thought content will be affected, rather than the pronunciation. If the hearing loss is through middle ear defects the bone conduction path is of increased importance and so the masking effect of external noise in ordinary circumstances is reduced. Thus the individual may actually be able to hear better than the normal in cases of noisy surroundings. He tends to reduce the intensity of his own voice in these circumstances lower than that of the normal. The speech of the person suffering from nerve deafness is distinctly different. If the loss is acute, he cannot hear his own voice by either air or bone conduction. If the loss is less acute, he may hear something by both paths. In these cases the hearing fails first on the high frequency range, which includes the formant tones for the fricative consonants, especially the voiceless [s, f, θ, ʃ]. These sounds tend to be lost in speech and confused in hearing, and the progressive stages of loss involve the explosive stages of the stop consonants, the voiceless stop consonants, the voiced stop consonants, and finally to the vowels and voiced continuant consonants. The general effect on the speech is a slurring of the clearness of the

separate speech sounds as well as a lack of control of the durations and separations of the various words. The unstressed syllables and words are weakened or even lost, and so much of the clarity of the thought sequence is obscured. The child born with nerve deafness is not necessarily mute but the speech is usually unintelligible unless it is taken in hand and trained in the proper methods by some combination of visual and tactual stimulation.

CHAPTER VIII

THE EXPERIMENTAL STUDY OF VOICE

§ 33·1. It is proposed to discuss here the more important experimental methods of studying voice from three major standpoints: the acoustical properties, the physiological action and the perceived sound-content. It is impossible to give an exhaustive historical account of the methods or to describe any in detail. Reference should be made to the bibliography for the sources of the methods, while only the techniques of particular importance are here given special consideration. The methods directed to the study of the acoustical properties of voice may be grouped under three headings. These are firstly, the methods of recording, secondly, the methods of analysis, and finally, the methods of synthesis.

Recording

§ 33·2. The methods at present available for recording voice are numerous and of varying accuracy. Probably the least accurate is the manometric flame, which gives at best a highly distorted presentation of waveform by variations in the flame-volume. Kœnig. This method is superseded by the much more accurate methods which have been developed since that time. The kymograph remains a valuable instrument, especially for giving qualitative information concerning the air-movements in oropharynx and nasopharynx and the slower changes in the air pressures in the vocal system. Rousselot, **117**; Marey, **116**; Scripture, **33, 118**; Wichardt, **36**. It is not accurate in recording the high frequency components of sound waves, but it is a good means of indicating the duration of continued voice and the changes

in air movements. The early types of photographic recording by successively more accurate means have included the phonodeik, Miller, **5** ; the mirror oscillograph, Metfessel, **29** ; and the sound film, Scripture, **348** ; and they culminate in the use of the cathode ray oscillograph. Calzia, **13** ; Curry, **14, 15** ; Gemelli, **284** ; Morris, **6** ; Parr, **8**. By this means the sound waveform, as transmitted by the calibrated microphone and amplifier, is recorded as a wavy line on a moving photographic paper or film. The shape of the line represents the vibratory motion in space and time of a molecule of air in the path of the progressive sound wave. An auditory record of voice can be obtained by the indirect method of recording on to a wax disc, which is afterwards used to produce a die for stamping replicas, or by the direct methods lately devised, which utilize a metal or glass disc coated with a thin and semi-plastic layer of, for example, cellulose acetate, cellulose nitrate or gelatine, which may be hardened at once by treatment with chemicals. This record may be replayed immediately without processing. Finally, the great industry which has grown around the sound film cinema has developed that method of recording and reproduction to a high degree of accuracy.

Analysis

§ 33·3. The technique of analysing sound waves into the characteristics of frequency, intensity, duration, quality and phase has not reached such a stage of perfection. Since the characteristic of the sound wave in speech changes from cycle to cycle, the desirable analyser would be one giving a complete analysis of each cycle in the duration of the cycle. This is naturally an extremely difficult task to accomplish. The earliest attempts at analysis utilized Helmholtz resonators, sharply tuned to single frequencies. Helmholtz, **2** ; Gage, **18**. By this means the presence in a complex sound wave of a component of the same frequency as that of the resonator could be easily detected. Little or nothing could be discovered about the relative intensities and phases of the

various components detected by this method. Moreover, the time taken to perform a complete analysis required the maintenance of the sound wave constant for a long period of time. Mathematical analysis can be performed upon a graphical record of the single cycle of the waveform, but naturally it must be repeated for each cycle and the time taken is quite long. The significance of the sound wave for a vowel is essentially the gradual change during the duration of the vowel sound. Fourier analysis on the harmonic scheme, or Vercelli analysis on the inharmonic scheme, have been made by various workers. Henrici, **21**; Marro, **28**; Sacia, **32**; Lewis, **65**. More recent electrical and mechanical methods have brought the time required more within the necessary limits, but even then they are by no means as rapid as desirable. The spectroscopic analyser is an ingenious method using a sound diffraction grating similar in principle to the grating used in spectroscopy to study the structure of a given sample of light. It is apparently rather difficult to work and requires certain conditions of constant temperature and humidity and, moreover, does not give a very rapid response. Meyer and Thienhaus, **30**. The most recent development in these matters of sound analysis utilizes a purely electrical method whereby the frequency range likely to contain the component tones of the speech sound under examination is scanned rapidly and the components of the waveform are shown up as deviations of the response-level for the given frequency. Freystedt, **17**. The circuit is usually coupled to a cathode ray oscillograph so that the spectrum of the component tones can be photographed from the image on the fluorescent screen.

§ 33·4. **Quality.** The above methods of analysis are concerned mainly with determining the quality of a given sound waveform, that is, the number and relative frequencies and intensities of the component tones of the wave. The variability of the quality from cycle to cycle in a progressive wave for a vowel is shown in a sample from one of these analyses. In connected speech the pattern in the progressive

waveform for any speech sound shows a sequence of, firstly, a short introductory period of atypical cyles of transition from the preceding speech sound or the silence, then, secondly, the main period of typical cycles which identify the speech sound, and finally, the terminating period of atypical cycles which link with the following speech sound or die away into silence. Gemelli, **284**, p. 7. A maintained sound, such as a sung vowel, may continue indefinitely on the second stage with typical cycles, which may be repeated without substantial change from cycle to cycle. The dynamic pattern of an average cycle of a voice waveform appears to be that of a dominant fundamental and an extended range of components whose intensities are modified in a pattern of usually three or more peaks of intensity maxima over the frequency range up to about 3,000 cycles. Kucharski, **302**; Gemelli, **284**. Sometimes the fundamental is not dominant and, moreover, the harmonics in the upper frequency range may change over from one to another without much effect on the quality. But in the low frequency range the harmonic structure is definitely established. The acoustical pattern of the waveform is therefore that of a complex sound having a wide range of harmonics which has passed through a series of at least three band-pass filters, each more or less sharply tuned to a given frequency region. The mechanical picture is that of a complex vibratory system (the vocal cord mechanism) coupled to a variable system of resonators and loads (the cavities of the vocal system).

§ 33·5. **Pitch Recording.** A number of accurate methods of measuring frequency and pitch are available, beginning with the laborious and slow method of measurement of the fundamental period from the kymograph or photographic record against an indication of time, usually in the form of hundredths of a second. More recent methods give a visible, immediate, photographic record of frequency on moving paper or film in the pattern of a wavy line, the vertical displacement of which corresponds to the rise in frequency above a given zero level. Ordinates of frequency and pitch

can be recorded on to the trace, and thus the intonation patterns for a given passage can be shown in the form and inclination of the line. An earlier method used a stroboscopic principle. Metfessel, **29** ; Tiffin, **35**. The more recent method utilizes an electrical circuit devised to indicate the frequency of an electrical supply and improved by various means to be applied among other uses to the recording of speech and voice. Obata, **31** ; Hunt, **23**. These methods give accurate and rapid results and are of great value in the study of voice.

§ 33·6. **Intensity.** The measurement of the intensity of sound is most easy. It is possible to measure the pressure-variations in a sound wavefront with the aid of a calibrated condenser microphone and an amplifier coupled to a cathode ray oscillograph. In this way the pressure changes are represented as variations in the vertical line recorded from the oscillograph. But it must be assumed rather arbitrarily that the intensity of the sound wave is represented by the amplitude of displacement from the zero level, and this depends upon the number and respective phases and frequencies of the component tones. Thus, for example, in the waveform for the vowel [α] the component tones are close together in frequency and phase, so that a cycle of the combination wave begins with a considerable amplitude of displacement and soon dies away. The most satisfactory method of estimating the intensity is thus to measure the peak amplitude of displacement, and this can be done by means of a peak voltmeter coupled to the condenser microphone, or by estimating the maximum excursion of the cathode ray oscillograph spot. These estimations can be made also on a logarithmic basis, so that the extended range of intensity can be compressed in the decibel scale. Crandall, Sacia, Wente, **32**.

Synthesis

§ 33·7. The history of the attempts to synthesize voice goes back probably further than that of analysis. The early work

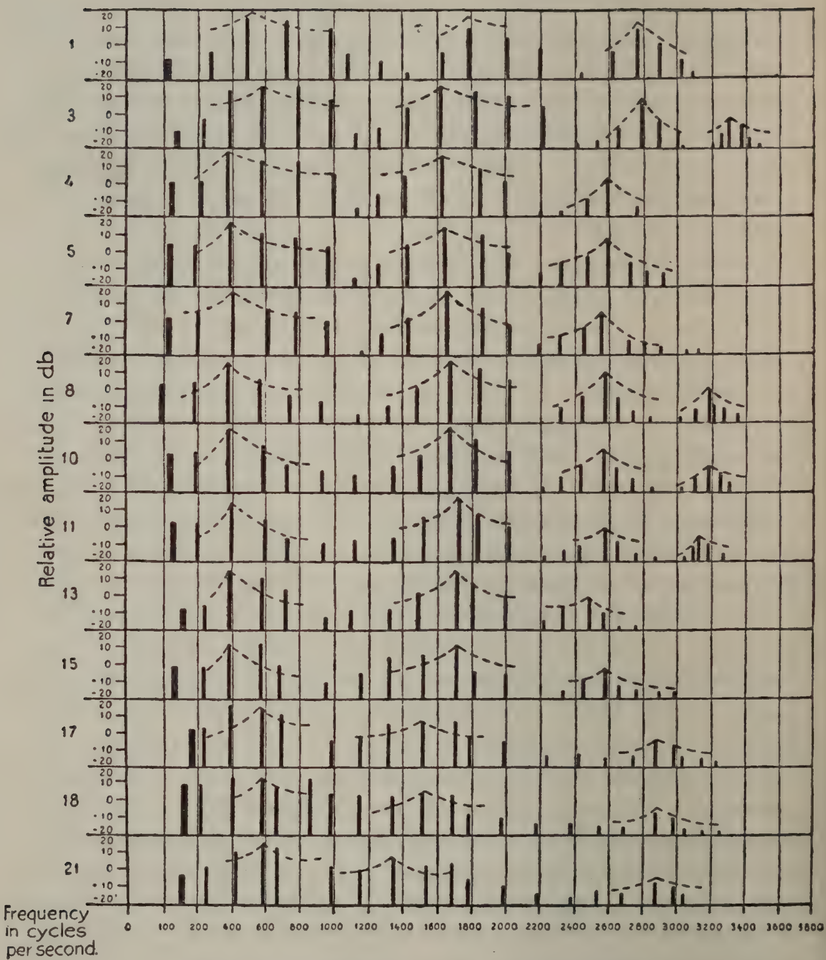

FIG. 18. The analysis of the vowel [α] (Gemelli).

of von Kempelen, **232** (1791) was mainly directed towards the synthesis of voice by means of models consisting of variously shaped resonators excited by the sound from a vibrating reed. Later works followed roughly the same lines, and it is possible only to note here the outstanding work of Paget, who is probably the most successful of all in the construction and manipulation of these models, and of Ewald, who was most successful in constructing models simulating the physiological and mechanical action of the larynx. It is noteworthy that the most successful imitation of the voice is made with a reed-tone having an extended range of upper harmonics as a substitute for the larynx. The manipulatory skill is probably the main factor in the success of Paget with the synthesis of the words [mαmα, lailα], and so on. Attempts have been made also to synthesize voice by using an electrical circuit generating a fundamental and harmonics, whose frequencies and intensities could be altered. The complex electrical wave was fed into a loud-speaker and thus converted into sound. Stewart, **358**. The difficulties in achieving a natural voice by this method lie naturally in the manipulation of the transitions from one speech sound to another, as well as the production of the three periods requisite to the true character of a progressive speech sound. This would be the case with any method incapable of producing the requisite sequence of atypical, typical and atypical cycles. More recent investigations with a human larynx excised from the cadaver have been conducted with the view to discovering the mode of vibration of the vocal cords. Travis and Buchanan, **375**; Hartmann, **287**; Müller, **315**; Trendelenburg, **382**. It must be remembered in these cases that the dead larynx excised from the cadaver does not function necessarily like the normal larynx, especially in point of the finer movements of the larynx muscles. Accordingly, it is necessary to study the results of these experiments in conjunction with those performed on the normal larynx in action in the living body. Indeed, the experiments on the normal larynx are always preferable.

The Physiology of Voice

§ 34·11. Experiments concerned with the physiological mechanism of the human voice are very numerous and have a long history. It is convenient to consider them under three headings: those directed to the measurement of the anatomy; those directly concerned with the analysis of the physiological mechanism; and those directed towards the synthesis of the voice. While a great deal of statistical work has been done on the ethnological variations in gross anatomy, relatively little is known definitely concerning the minor anatomical dimensions, as, for example, the dimensions of the vocal organs among different races and types. It is unlikely that these anatomical differences are very significant as far as the general outline of voice production, as we know it, is concerned, but they may be very important in the determination of the precise voice quality peculiar to each person. Apparently, in the study of palatal dimensions interesting sex differences can be found as a recurrent characteristic. Kaiser, **300**. The palatographic technique permits of measurement of the dimensions of the mouth cavity and walls and the areas of contact between tongue and palate for the articulation of certain speech sounds. Witthoft, **37**. The external dimensions of head and neck can be recorded photographically, and the internal dimensions of nasopharynx, oropharynx and larynx can be estimated very accurately from the X-ray photographs. The dimensions of the larynx, and especially the length of the vocal cords, can be estimated very accurately also by means of the very ingenious microscope system, which can be used on the living person. Trendelenburg, **377**. Internal photography of the larynx, provided the possible optical aberrations are determined, will permit also of the measurement of the dimensions of the larynx and oropharynx as well as of the epiglottis.

§ 34·12. The recording of the physiological mechanism of voice has been greatly facilitated by the recent advances in

photography and X-ray technique. **13, 25, 26, 27, 264.** It is now possible to take high-speed external motion pictures of the person with a synchronized sound-film record. It is also possible to take motion pictures of the internal larynx movements, either continuously or stroboscopically in apparent slow-motion. **285, 286, 327.** The method of high-speed internal larynx cinematography is now capable of taking 4,000 pictures per second. Herriott, **288.** It is possible to take X-ray cinematographic pictures of the mesial, sagittal section of the head and neck at speeds up to 16 or 24 frames per second. **255, 296, 337, 342, 357.** At the same time other physiological changes can be studied. The changes in blood-pressure may be continuously recorded. Stokvis, **34.** The thoracic and abdominal movements in breathing may be recorded pneumographically with the quantity of air expelled. The actual movements and dimensions of the thorax and abdomen can be recorded by X-ray technique in a special method called X-ray kymography. Scott, **346.** The action currents from the respiratory muscles and the larynx may be recorded photographically. Stetson, **354.** Action currents from the laryngeal nerves in dogs have been recorded, together with the sounds emitted when the animals come out of the anæsthetic. Lindemann, **305.** The breath-pressure from the mouth and the quantity of air issuing from the nose can be correlated with the intensity of the vibration in the nasopharynx. Borel-Maisonny, **309.**

§ 34·2. **Laryngoscopy.** The analysis of the vibratory action of the vocal cords has been greatly facilitated by the recent developments in instruments. It is now possible to study laryngeal movements on the living subject without great inconvenience to the subject, and even in special circumstances while the subject is articulating normal connected speech. (Russell's fonofaryngoscope.) This instrument, consisting of a special form of optical laryngoscope with very narrow tubes, can be placed in position without impeding the normal articulatory movements and can thus give an unobstructed view of the larynx during normal

phonation. The recent larynx photography performed at the Bell Telephone Laboratories, New York City, under the direction of Steinberg, has shown certain interesting results. (Personal communication to the author.) It confirms the vertical displacement of the larynx during the singing of higher pitches and also shows the changes in the durations of the respective phases of opening and closure of the cords in accordance with changes in the frequency and intensity. This confirms in the main the results obtained by stroboscopic methods. Tarneaud, **247**. Since the discovery of the principle of stroboscopic action over 100 years ago, the study of the vocal cord action has been greatly advanced by the stroboscopic examination of the larynx during singing of a maintained tone. There are various types of mechanical stroboscopes, mostly utilizing a variable-speed motor rotating a disc perforated with slits which interrupt the light beam from a powerful light source and focussed on to the frontal mirror of the laryngologist. Tarneaud, **247**. More recently types of electrical stroboscopes have been devised in which the voice frequency controls the speed of the illumination flashes and the light source consists of a small discharge lamp mounted into the side of the laryngoscope near the larynx itself. Various electrical circuits can control the phasing of the illumination so that the motion of the cords can be viewed in any phase of the vibration cycle. Kallen, **26**.

§ 34·3. **X-rays.** The X-ray study of the physiology of voice has been developed by many workers with varied degrees of success. Russell, **241, 339–41**. It must be emphasized in this connection that certain precautions are necessary to ensure an accurate record of vocal movements or positions. It is desirable that the exposure time be very short—$\frac{1}{60}$th or $\frac{1}{120}$th second at least—and that no attempts to use opaque meals should be made. It is very important that the subject should be as little disturbed psychologically as possible in the circumstances. For purposes of comparison between subsequent X-rays, it is desirable that the subject keep about the same position and tilt of head, but that does

not mean that the head should be immobilized with a harness. The psychological effect of such a harness on singers is bound to be considerable. With the X-ray picture a synchronized cathode ray oscillographic record of the sound waveform and an acoustic record of the sound should be made. Curry, **269–72.** The X-ray method is the only way of taking a picture which will represent the mesial, sagittal section of the vocal system during normal phonation. Portman, **240.** With the modern apparatus of the rotating-anode tube and the high-speed screens, it is possible to take very clear pictures of the larynx and the vocal cords during normal voice without the need for any opaque material. By means of the new and ingenious technique of X-ray tomography, by which the outline of deep structures can be shown up without the superposition of different images, the frontal section of the larynx with the outlines of the vocal cords and the ventricular bands can be seen. Canuyt, *et alia*, **267.** This method has already confirmed the important part played by the ventricular bands in voice. A combination of the two methods would give a two-dimensional picture of the larynx.

§ 34·4. **Larynx Models.** The synthesis of voice has been attempted on many occasions, both with excised larynxes and with mechanical models. Early attempts at stimulating vibration in the dead larynx almost invariably relied upon the stretching of the vocal cords with weights in the delusion that the vocal cords were stretched to produce higher pitches. Müller, **235.** The quality of the sound produced with the dead larynx is invariably a harsh variety of the vowel [a]. This is probably the nearest approximation to the larynx sound uninfluenced by the resonance action of the vocal cavities. The waveform of this sound shows an extended range of harmonics of the fundamental and more or less of equal amplitude. Naturally, the dead larynx cannot be expected to undergo the changes in position and outline that occur in the normal under the influence of the internal and external muscles. As has already been seen, the larynx

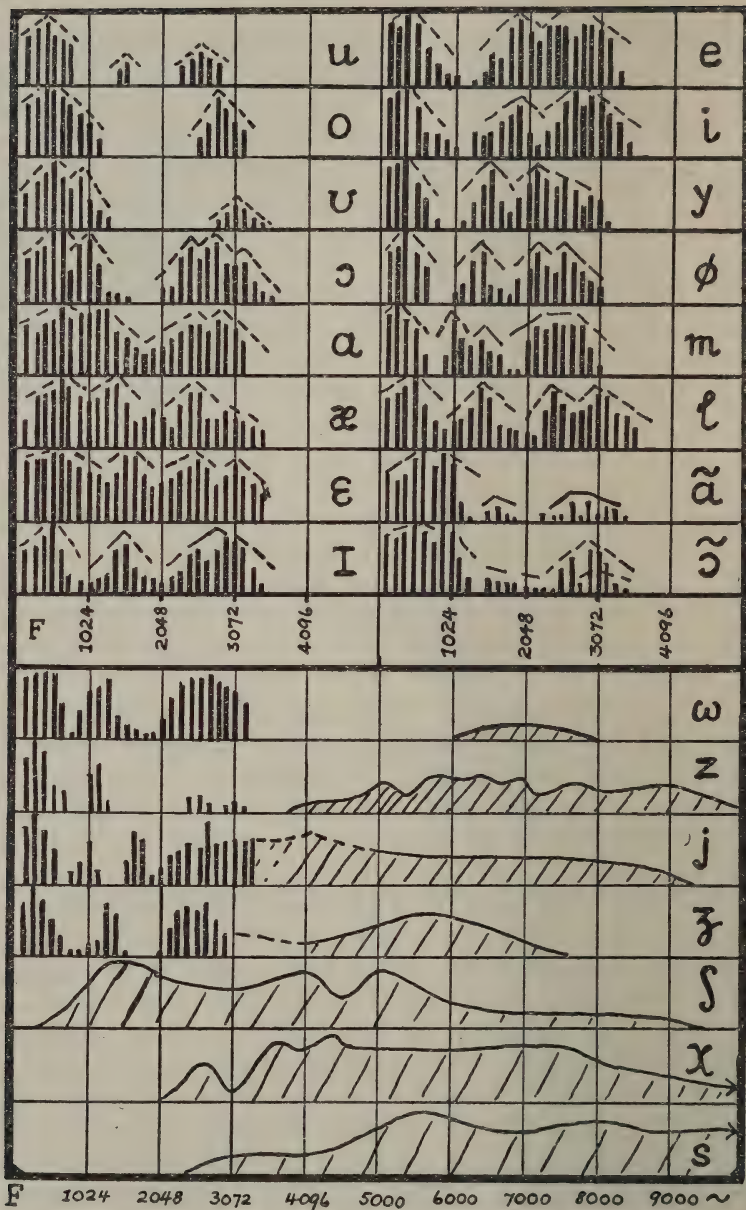

FIG. 19. Harmonic spectra on voice-pitch of 128 cycles (Barczinski).

changes in shape and action for each sound and frequency. Thus the study of the dead larynx is a poor substitute for the normal. Nevertheless, in the excised larynx the effects of stimulating the various muscles can be studied in gross form. Kaiser, **299**, p. 15. Thus in investigation on the larynx of a dog, stimulation of the posterior cricoarytenoid muscle resulted in the opening of the glottis roughly in the form of a diamond with the points directed to the rear and front of the vocal cords. Stimulation of the lateral cricoarytenoid muscles closed the glottis save for a triangular gap between the arytenoids. Stimulation of the cricothyroid closed the glottis also. The thyroarytenoid muscles after weak stimulation closed the posterior glottis, and after strong stimulation closed the plica vocalis also. Stimulation of the two vocal cords raised the pitch to a height which could not be attained by one cord only.

§ 34·5. Unfortunately many of these early experiments were carried on without the simultaneous recording of the sound waveform by the accurate means afforded by the cathode ray oscillograph, so it is impossible to determine the harmonic composition of the sounds produced. More recently, somewhat similar experiments have been directed to an ingenious optical method of recording the movements of the vocal cords in the stimulation of the dead larynx, simultaneously with the recording and analysis of the sound produced. Trendelenburg, **380**. By this method the duration of the closed phase and the phase of opening and closing of the cords can be recorded on photographic paper. If allowances are made for the necessarily abnormal conditions of the dead larynx, the results confirm the findings of the stroboscopic examinations of the living larynx.

§ 34·6. Probably the most successful models of the larynx actions were those devised by the physiologist, Ewald, and duplicated by later workers. Weiss, D., **391**; Wethlo, **395**, **396**. These models are commonly called 'Polsterpfeifen'—a name descriptive of the manner of construction. The vocal cords are represented by rubber wedges or wedge-shaped

rubber bags filled with air, and protruding into the lumen of the tube which represents the trachea. Some models can be actuated with air coming from above and below the rubber 'pillows,' while others are unidirectional. For a certain degree of the pressure together of the wedges and a certain air pressure from below, the models will produce voice by the separational vibration of the wedges, with a periodically interrupted flow of air between the edges. The quality of the sound is agreeable and similar to that of the human voice singing the vowel [o] or [ʌ]. If the air pressure is increased, the intensity of the sound increases up to a maximum, after which increased air pressure reacts to lower the fundamental pitch. An increase of the pressure together of the wedges, and hence the stiffness of the system, reacts to raise the pitch. Ewald showed great ingenuity in constructing these models, in some of which the pillows consisted of air sacs which could be inflated to different degrees of pressure, and hence rigidity of the edges. This simulated the changes in rigidity of the thyroarytenoid muscle. At the same time the degree of firmness of contact between the edges could be varied, and the depth of the faces in contact could be increased, thus simulating further the conditions obtaining on the living larynx in phonation. It is probable that these models came nearest to the true larynx action in the living body.

The Perception of Voice

§ 35·1. In the experimental study of the perception of voice the majority of the work has centred round the perception of pitch and intensity. In the study of pitch perception there are two considerations involved. These are, firstly, the accuracy in judging absolute pitch and, secondly, the accuracy in judging pitch change and intonation. The accuracy of judging absolute pitch depends upon the duration and the intensity of the tone; low-pitched sounds must last longer than high-pitched sounds for accurate judgments, while the accuracy tends to decrease with great changes in intensity. Stevens and Davis, 47, p. 101. Modern methods

of investigation include the audiometer, the electrical filters, sound generators, which can be altered in frequency, intensity and phase, and recorders of high fidelity and accuracy. Action currents from the auditory nerve in animals can be recorded, together with the sound waveform incident upon the ear. Stevens and Davis, **47**, p. 376. The anatomical and histological structure of the inner ear and the cochlea have been investigated carefully in the case of patients, for whom the hearing characteristics had been measured with the audiometer before death. Guild, **56**. The physicist and the communication engineer have become interested in hearing from the standpoint of the improvement of the telephone and radio and the comprehension of the mechanical action of the cochlea. Fletcher, **40**. The physical properties of the ear and the psychological nature of loudness, pitch, duration and quality have been investigated in many different ways by a great many investigators. Stevens and Davis, **47**.

§ 35·2. With the increasing interest in the matter of cortical functioning, the localization of the functions of speech in the areas of the cerebral hemispheres has been studied in various ways. The localization of motor functions of voice in given cortical areas can be deduced from the pathological states of these areas in cases of lesions or vascular disorders. The available material of aphasia shows that the localization is by no means sharply distinctive from one area to another, especially as far as the co-ordination of functions is concerned. Strasburger, **359**. Other investigations have been concerned with the direct stimulation of definite areas of the cortex during cerebral operations, which have exposed the surface of the hemispheres. Penfield, **325**. In these cases the area stimulated was near the pre-Rolandic gyrus, and therefore involved the recognized motor centres for the bodily movements, including those of voice. Stimulation of these areas evoked voice in varying degrees of involuntary nature. The histology of particular areas of the cortex, especially areas 56 to 66 (Brodmann), including the so-called Broca's area, has also been investigated. Kreht,

301. A sensory cortical representation of the vagus nerve has been found. Bailey and Bremer, **254.** So far these investigations are not very conclusive for the functions of the so-called association areas of the cortex.

§ 35·3. Recently the increasing interest in the study of the action potentials, which can be recorded from various areas of the skull overlying the recognized cortical areas, has led to a certain study of the correlation of these findings with the psychological and physiological states of the individual. The great complexity and variability of the patterns so obtained has prevented much localization of this correlation. It is becoming apparent, however, that widely variant patterns of these action currents are correlated with different forms of motor activity or emotional and psychological states. Travis, **376.** These factors may be associated with the incidence of speech disorders or of psychoneuroses, especially schizophrenia. It is obvious that the complex actions of normal voice, which involve a high degree of correlation, must involve functional activity of a great many parts of the cortex, as well as selectively graded functionings of the various levels of central nervous control at the medulla and cerebellum. It is quite possible that certain features of a given spoken language, especially the intonation patterns peculiar to that language, may become almost reflex and automatic in a given individual, and thus may be controlled rather by the cerebellum than directly by the cortical association areas. The interrelationships of the cortex and the cerebellum are only just beginning to be understood. Lashley, **303**; Marburg, **311**; Mettler, **312.**

CHAPTER IX

DISORDERS OF VOICE AND SPEECH

§ 36·1. In the study of the disorders of voice and speech the term disorder is comprehensive, including not only the description of the abnormal state, but also the underlying cause. The abnormal state is more properly termed a defect. Certain defects may be localized in speech only, while the more general disorders involve all manifestations of voice, including speech. In the classification of the disorders an attempt has been made to follow the lines of a fourfold consideration. This is whether the disorder is based upon firstly, anatomical defects; secondly, physiological defects; thirdly, psychological defects; or fourthly, linguistic defects. Naturally, in the majority of the cases the etiology is not so sharply localized as to belong exclusively to only one category. The main value of the classifications is to be found in the recommendations for therapy, which will vary with the particular emphasis put upon the respective etiological factors. Within the limits of each category the various disorders may be grouped according as they are due to congenital or developmental causes, and in each group an attempt is made to separate the organic from the neurological and from the endocrine disorders. It is not the intention to discuss the surgical treatment for these defects, but rather to summarize the trends of opinion on each disorder and make references to the available sources of information. Following the classification adopted by the American Speech Correction Association, the first group will be the disorders known under the group of DYSLALIA, the second group will be that of DYSPHONIA, the third group that of DYSPHEMIA, and the fourth that of DYSPHASIA. Robbins, **168**.

§ 36·12. **Child Speech.** Since children constitute the majority of the cases of speech disorders and the onset of the disorders is generally in childhood, it is important at this stage to realize the complex nature of the child's adjustment to the learning of speech. It is a common concept that children handicapped by delayed or defective speech are either deaf or mentally deficient. For this reason it is probable that many children, thus handicapped, are wrongly labelled as dysphasic or feeble-minded, when specialized training of their speech may often effect a considerable change in their adjustment to society. Stinchfield and Young, **117**, p. 5. The growth of speech in children is a forced process cultivated under pressure from social conventions. The early sounds of a child up to about nine months are responses to biological needs or states of comfort or discomfort and libidinal gratification. Lewis, **153**. Just before the age of nine months there is a pause in the process and then a period of ' speech readiness ' (Sprachbereitschaft), which lasts until about two years. This period is the most promising for the development of speech. Stinchfield and Young, **177**, p. 18. Speech of some sort by imitation and purposive activity should be expected in the normal child at this period. The earliest words, which are nearly alike in sound and meaning in most languages, are usually formed of single or double syllables having [p, b, t, d, n, m, w] and a vowel. This is favoured by the existence of traditional nursery words such as [mɑmɑ, pɑpɑ, dɑdɑ]. The process of development involves an increasing reference specifically to parts of the whole concept and the transference of meaning from one to the group of objects. In early life the child's speech has an excess of front consonants and reduplicated forms, hence the way of elisions and substitutions occurring in the faulty imitation of adult speech. In groups of a stop and a continuant consonant, the less positively sensed continuant is lost. A labial and a continuant consonant are assimilated to the original or a similar labial, thus: [sw→f, ʃw→f]. Consonants that are novel or more recently learnt are replaced by those

coming earlier in the child's life, usually front consonants. In assimilation the general principle is the commencement or termination of all syllables of the word with the same sound, thus: [tsʊkə→kʊkə]. Lewis, **153.** These substitutions are most similar to those found in cases of verbal aphasia, in which the ontologically later processes of speech are replaced by the ontologically earlier speech responses or sounds. Head, **231,** vol. 1, p. 516ff. It is important therefore to regard the disorders of speech from the functional physiological standpoint of the brain in action. The adaptability of the child to the adult world depends upon the ordered sequence of environmental adjustment in speech above everything else.

§ 36·2. **Diagnosis.** In the study of vocal disorders it is very evident that the diagnosis should be made as early as possible and should have the services of as many specialists as possible. In particular, the services of the oto-rhino-laryngologist, the neurologist, the phonetician and the psychologist should be available and a thorough physical examination should be a customary preliminary. Wherever possible, the very valuable instruments of diagnosis recently developed, such as the stroboscope, the audiometer and the various recording methods, should be available. The diagnosis must be thorough and progressive, even though in rare cases an obvious cause of the disorder becomes evident quickly. It will be found that the diagnosis needs to be progressive, that is, the condition will become more evident in later examinations. In the phonetic analysis of the existent speech, if any, the major considerations will be the types of respiration, phonation, articulation and language. For this reason it is very necessary that the phonetician should understand and be able to use the instrumental means of studying these factors. It is also desirable that he should be well acquainted with the phonological history of the language in question. The psychologist should take up the matter of the case history of the patient, parents and environment, with special attention to any history of previous

speech disorders in the family. He should be capable of dealing with any matters of abnormal psychology and should be experienced in clinical psychiatry and psychoanalysis. Meanwhile the physical examination will presumably show any organic or neurological pathology and specialist assistance should be available in the event of any such disorders. Only after a thorough and progressive examination should any recommendations be made for therapy.

§ 36·3. **Prognosis.** The prognosis in cases of vocal disorders is very variable. Cases of brain-lesions or congenital pathology or malformation, involving surgery, are really outside the field of the speech therapist to handle alone. Moreover, the prognosis in these cases is not good. Opinions vary greatly in the prognosis of stuttering, which forms the bulk of the cases of speech disorders encountered. Each case must be considered on its own merits. The therapeutic approach must naturally vary considerably with the case, and the success of the treatment depends in no small way upon the efficiency and versatility of the therapist. The detailed lines of the therapeutic procedure must be worked out individually by the therapist, since any indications given by those unfamiliar with the particular case can be only generalizations. It is advisable, therefore, that the therapist be familiar with all the variant theories of the etiology of speech disorders that are current. Any particular theory tends to be based upon especial case histories which may be similar to that of the case in point. The so-called process of ' growing out ' of stuttering probably does not occur. In reality, the patient effects his own cure or the provocative circumstances change or vanish. The patient is generally dominated by emotion, usually that of fear, and hence there are well-defined reactions of a physiological nature in the form of disturbances of breathing, metabolism, eliminatory processes, etc. Confidence and an experience and background of successful normal speech should be established by identifying the precipitatory causes of the disorder and indicating successful cases and the necessity of the full co-operation of the patient. The duration

and difficulty of the therapy should not be underestimated, nor should the case be undertaken lightly. A confident manner on the part of the therapist is an essential factor in the therapy.

Stuttering

§ 36·4. **Etiology.** Consideration of the etiology of the disorders is the most complex and difficult part of the discussion. The etiology of organic, neurological and endocrine disorders may be described in the following discussion of individual types. But the theories of the origin of stuttering (Spasmophemia, Stotteln, Bégaiement) are manifold and variant, and it is advisable to give them some general consideration at this stage. There is a certain consensus of opinion that stuttering is a psychogenic neurosis, which is usually initiated in childhood, and which, probably by reason of some debility, either organic or neurologic, of the speech organs, has fixed upon the activity of speech and voice. Heltman, **194**, p. 95. The factors tending to predispose the neurosis in the way of a speech disorder may be transitory and may disappear in later life. The disorder is characterized by a variability compatible only with a psychological and not with a physiological etiology. The nervous reaction upon the health of the individual may produce secondary symptoms of disturbance in breathing, metabolism, feeding, muscular tonicity, emotional stability, endocrine balance, vaso-motor balance and other organic and physiological processes. It is apparently most frequently initiated at about the age of two and a half years when the speech process is becoming established, or again later at about eight years when the speech is well established in cases of emotional strain, or finally, later and more rarely in adult life as a recurrence of the childhood disorder or under emotional strain. It is apparently much more common in boys than in girls (from 3 to 1 to 5 to 1 being the ratio).

§ 36·51. Fortunately the era of anatomical theories of the etiology of stuttering is now past, but in the nineteenth

century the surgical treatments were various and drastic. The disorder was attributed to malformation of the tongue or dysfunction of the articulatory organs and all kinds of surgical excision and treatment were performed. Pieces of the tongue were removed and various muscles were severed; it was pierced with needles, and cauterized and blistered with all kinds of caustic dressings and injections. It is quite evident that in cases of success by these methods the real cure was the physical shock. The physiological theories which later became current tended to centre round the secondary symptoms of associated disturbances. The disturbances of respiratory rhythm was observed by many. Gutzmann, **230**; Fletcher, **144**; Travis, **251**; Robbins, **169**. Vasomotor disorders and changes in the brain volume were observed. Robbins, **169**. Disturbances of the vegetative system have been considered as a factor. Seeman, **207**; Sovak, **208**. A great deal of attention has been paid to the question of the dominance of one hemisphere. Orton, S. T., **159**; Travis, **251**; Bryngelson, **190**. This is primarily a physiological and organic theory and is associated with the problems of left-handedness, inversion of right-handed actions such as writing, the dysfunction of the left vocal cord in singing and left ocular dominance in vision. It is also connected with the question of the much-disputed area in the left cerebral hemisphere, known as Broca's area, and supposedly situated in the posterior part of the inferior, frontal gyrus for right-handed persons in the left hemisphere and for left-handed persons in the right hemisphere. This is histologically only an association area, since after destruction of this area all the separate actions of speech are possible, but the complex correlation of these separate actions is no longer possible. There may be differences in the cardiac rhythms of stutterers constituting a sexual distinction. Palmer and Gillett, **204**. Stammering may be associated with an allergic disorder. Seeman, **207**; Sovak, **208**. The importance of faulty hearing and stuttering is also stressed. Röse, **170**.

§ 36·52. **Cerebral Dominance.** The association of stuttering and cerebral dominance and left-sided functional precedence merits closer discussion if only by reason of the mass of published studies of this question. It is considered in this theory that the stutterer does not have the dominant gradient of the unilateral right-handed person. He is often ambidextrous or left-handed. If he is compelled by conventional training to become right-handed, his brain-dominance is disturbed and the speech disorder is initiated. The most recent statement of the position reached in this study gives the following conclusions. The dominance is not easily measurable by the use of predominant leads in attempted simultaneous movements. Localized, unilateral, cortical dominance is a genuine functional reality as related to handedness, but there is no evidence for complete hemispheral dominance involving all cortical functions. Mixed dominance may accompany disorders of the central nervous system. This handicap may be overcome by an individual with enough resistance to or tolerance for this particular cause of neurosis. Shift of handedness has highly variable results as far as concerns speech disorders, and the improvement upon reversion to the natural handedness is not so marked as would be expected. Jasper and Raney, **195**, pp. 151–65. The association between left-handedness and eneuresis is not significant. Michaels, **201**, p. 763. There is apparently no significant correlation between handedness and reading ability. Pace, **202**, p. 210.

§ 36·6. **Psychopathology.** The psychological and psychoanalytic approaches to the study of stuttering have given rise to many related theories of etiology. It is impossible to do more than summarize the main opinions. In general, the opinion is that the disorder is a fault of social adjustment, resulting in a retreat from the social use of speech or a faulty action of the speech processes. There is no special evidence of the pre-existence of what may be called an inferiority complex, but most cases of the disorder show some degree of repressed aggression which, on cure, becomes quite strong

aggressive attitudes. One theory associated the disorder with a vocabulary phobia, taking note of the tendency towards obscenity among boys rather than among girls. Galant, **193.** The problem of auditory amnesia was suggested as the possible cause of the loss or weakening of certain words. Bluemel, **138.** This does not take account of the transitory nature of the amnesia or the preoccupation of the patient with the task of speech. A somewhat similar theory attributed the disorder to visual centre asthenia on the assumption that the cue to speech was the image of the sound or word. Swift, **178.** The theory of cumulative conditioning took note of the fact that the stutterer can commonly speak well when speech is not used socially in communication. Fletcher, J., **144.** The primary origin is in a chance occurrence in childhood, and thereafter speech disturbances occur as the response to the stimulus of the social act. It is quite probable that imitation plays some part in the initiation of and relapse in later life into the stutter.

§ 36·7. The psychoanalytic approach to speech disorders has not been very systematic, probably because of the fact that in psychoses and psychoneuroses the speech disorder is only a part of the more important and fundamental disorder. Frankel, **131.** Moreover, the time and expense involved in analysis have probably prevented the study of the speech disorders by themselves. Nevertheless, the indications of the various schools of psychoanalysis on the subject are of great importance. They tend to stress the frequent indications of social maladjustment in cases of stuttering. The stutterer is afraid of the aggressive impulses, but there is found in his unconscious mind great oral aggression and sadism. Stuttering often begins in the late oral and early anal period in children who were difficult to train in toilet manners or who were repressed severely. An anal-sadistic attitude combined with a regression to oral auro-eroticism may occur. English and Pearson, **125,** p. **107.** In this connection neologisms may be designed to cover secrets often of a sexual nature. Coriat, **141,** p. **163.** The words and

letters may come to represent curious anal-sadistic fantasies. The given bodily symptom of the facial twitch or a momentary block of speech may be the expression of the discharge of the mental conflict and the direction taken by the discharge of the conflict is predetermined by the normal physical expressions of emotion. The social importance of good speech may be associated with the disorder in that the stutter may be initiated by the desire to avoid contact with society by using ridiculous or unintelligible speech. There is often a definite compensation from the stutter either directly from the unconscious expression of aggression or indirectly from the solicitude of the parents. The stuttered words may be related to particular psychic shocks, the memory of which is repressed. Blanton, **137**. This produces interference with general speech or speech on particular topics. Stuttering may be due in part to psychological conflict produced by bilingualism. Travis, **180, 213** ; Borel-Maissony, **198**.

§ 36·8. **Symptoms.** The symptoms of stuttering are greatly variable from one case to another. The spasms are marked by clonic and tonic contractions in the respiratory, phonatory and articulatory muscle systems. The normal respiratory synchronism of thorax and diaphragm is upset and severe cramps of the diaphragm and abdominal muscles are common. Stinchfield, **176**, p. 116. Laryngeal spasms may occur in which the vocal cords are tightly pressed together, causing inflammation and swelling of the tissue. Gutzmann, **230** ; Nadoleczny, **237**. Tonic spasms of the articulatory muscles may produce a clenching of the jaws or tight pressure together of the lips. These muscles may also undergo clonic spasms, producing an uncontrollable quasi-tetanic repetition of jaw and tongue movements. The subject frequently resorts to the use of a ' starter ' mechanism, such as a grunt, labial consonant, or a twist or other kind of contortion of the face and head to initiate the flow of speech. The physiological picture shows a general muscular hypertonicity with delayed reaction-times and an emotional instability. The psychological picture shows a general nervousness with

great variability of reactions towards different circumstances, a hypersensitivity to the presence of a social audience and a strongly repressed feeling of guilt towards various social actions and situations.

Organic Defects

§ 37·1. The anatomical bases of speech defects and disorders may be classified according as they are firstly congenital, or secondly developmental. The congenital defects are generally the result of failure of the union or development of the primitive structures in intra-uterine life. The most common of these is congenital cleft-palate, where the cleft may be complete, involving both the hard and soft palate, or incomplete, involving the soft palate or even only the velum. Cleft-palate is often accompanied by cleft-lip. It is important in these cases that surgical treatment be available as early in life as practicable, and before the speech patterns with the defective organs have become established. The precise details of the closure of the cleft are to be determined by the surgeon in consultation with the speech therapist, since the value of the surgery is essentially for speech and respiration. In some cases an obturator may be better than surgery. The essential requirement is that the nasopharynx should be able to be closed off from the pharynx for all except nasal speech sounds and the inspiratory phase of respiration. Von Thal, **248.** Another defect of similar effect on speech is the incomplete palate where the velum is too short to close off the nasopharynx. Surgery in these cases is often difficult, and may involve the raising of a protrusion on the posterior pharynx wall at Passavant's cushion to form a projection large enough to enable the velum to close the passage, which has thus been reduced in volume. Seth and Guthrie, **172,** p. 168. Injection of paraffin wax may be used to build up this protrusion. Other anatomical defects, such as deviated septum and atresia of the nasal choanæ, will affect the respiratory function as well as speech and may require surgery.

§ 37·2. The developmental types of anatomical defects likely to react badly upon speech may be considered in connection with the organs affected. The most common type is the dental defect of front or lateral open bite or marked malocclusion of the teeth. This may be either protruding anterior maxillary teeth with an underdeveloped mandibular arch, or receding maxillary arch with overdeveloped mandibular arch. Ramsey, **330.** In these cases the occurrence of lisping is almost inevitable. The cause of the disorder is usually persistence of the habit of sucking the thumb, while other defects may be the loss of the upper dental incisors and the late appearance of the permanent incisors. The type of the lisping is the reduction of the dental and alveolar fricative consonants to a variety of [s] or [l]. Incidentally, it may be remembered that lisping, or sigmatism, may occur as a purely functional disorder of a psychogenic origin or consequent upon a high-frequency deafness. Stinchfield, **176,** p. 38. Imitation may play a part in the incidence of the lisping, and, like stuttering, it may vary with physical health and the psychological situation. The psychogenic type is probably a regression to earlier habits. In high-frequency deafness the voiceless consonant [θ] is most frequently altered, since it has low audible intensity and the articulatory action is difficult to imitate.

§ 37·3. **Nasopharynx.** Developmental defects and disorders of the nasopharynx and the soft palate may radically affect speech. Nasal obstruction by polypi, deviated septum, turbinal hypertrophy or enlarged adenoids may completely close off the nasopharynx and the nasal quality necessary to the nasal speech sounds may be absent. Hence in English the consonants [m, n, ŋ] will sound like [b, d, g]. The surgical removal of adenoids may result for a while in a continuously nasal speech because the kinæsthetic control of the movements of the velum may not be adequate to ensure closure of the nasal passage which may be considerably enlarged consequent upon the removal of the adenoid mass from the posterior wall of the rhinopharynx. Mouth-blowing exercises are

necessary for such cases. Partial injury or paresis of the soft palate may result from surgical operation of that region or through localized lesion or pressure upon the pharyngeal nerves. There may even be a functional debility of the palatal muscles consequent upon diphtheria or adenoidectomy.

§ 37·4. **Laryngectomy.** The surgical excision of the tongue consequent upon carcinoma is fortunately rare, but cases have been reported which show the relative subordinate importance of the articulatory to the phonatory mechanism. In a case of complete excision of the tongue the subject was able to pronounce all vowels quite well. Negus, **238,** p. 418. Cases of the excision of the larynx consequent upon cancer are more frequent, and it is apparent that the phonatory action normally performed by the larynx may be simulated by vibration of the edges of the œsophageal tube under pressure of air forced from the stomach. The now well-established technique of œsophageal substitution voice is best illustrated by the following analysis of the action. Stetson, **356,** p. 132. A small quantity of air (2 to 5 c.c.) is swallowed into the œsophagus with the mouth and velum closed. Speech is divided up into short groups of two or three syllables and the pseudoglottis is formed by constriction at the œsophagus between the pharynx wall and the epiglottis. With practice the subjects become expert and the speech is fairly natural. The narrowing may even occur between the rear of the tongue and the pharynx wall to produce a relatively low-pitched, hoarse voice of weak power. Paget, **160,** p. 225 ; Scripture, **347,** p. 2. The laryngectomized patient may also be fitted with an artificial larynx receiving air from the tracheotomy opening in the front of the neck and conducting the sound into the back pharynx as near the larynx as possible. The artificial voice of this type is hoarse, relatively invariable in pitch and of moderate intensity.

§ 37·51. **Puberty.** Certain physical changes in the speech organs at puberty may react to a certain extent upon voice and speech. At puberty the male vocal cords increase over a period of about six months by about a third of their previous

length and the voice generally falls about an octave in pitch. Certain functional disorders may result from the attempt to produce the high pitches of the pre-pubertal voice with vocal cords whose mass has increased and whose stiffness has decreased. The posterior interarytenoid glottis may not close completely in phonation as a result of the growth of the laryngeal muscles, and the vocal cords may become œdematous and swollen by reason of the strained muscle action. In the female the pubertal changes are less noticeable. The vocal cords lengthen by some 3 mm., and there is a thickening and softening of the panniculus layer of tissue over the pharyngeal muscles and walls. In this case the vocal change is earlier and much less radical; moreover, it is much more smoothly accomplished. The voice drops about a third in pitch and becomes clearer and more characteristic of the female voice.

§ 37·52. Arrested and pathological sexual development may have a radical effect upon voice. The effect of castration before puberty is to prevent normal development of the thyroid cartilage, vocal cords and ventricular bands. The angle of the thyroid is less pronounced, the edges of the cords are sharper and less thick, while the capacity of the lungs and the expiratory force are equal to those of the normal. The voice may thus have the compass of the alto but the power and sustaining force of the baritone. There is generally no ossification of the cartilages and little loss of elasticity of the tissue with age. Negus, **238**, p. 433. Conversely, the effects of acromegaly, in hyperfunction of the pituitary gland, involve a deepening in pitch and roughening in quality of the voice, consequent upon a general enlargement of the larynx and a thickening of the mucous membrane, particularly over the epiglottis, vocal cords and ventricular bands, as well as changes in the tongue, uvula, soft palate, fauces and nose. Negus, **238**, p. 433. In cases of ateliosis there is no excessive growth, but rather a failure of development of the secondary sexual characteristics and a thin, piping voice of the child. In the female the arrested sexual development produces the

deep, manly voice associated with the other masculine characteristics. Seth and Guthrie, **172**, p. 202.

§ 37·6. **Endocrine Unbalance.** The general pathological effect on speech of endocrine unbalance is variable. Shafar, **352.** In the case of the thyroid glands hyperfunction rarely affects speech directly, but hypothyroidism constitutes a radical speech disorder. The voice becomes thick and gruff; the speech is slow and the pitch range is reduced. The whole thought process may be dulled and retarded in cretinism. Disorders of the thymus glands may exercise effects upon speech by local pressure on the nerves supplying the larynx, producing dyspnœa or aphonia. The parathyroids have no traceable effect. Tumours of the adrenal glands may produce speech disorders consequent upon the physical disorders of virilism or Addison's disease. The effects of the disorders of the pineal and pituitary glands upon speech are likewise secondary by way of the altered morphology or local growths producing nerve pressure.

Physiological Disorders

§ 38·1. Speech disorders of the more specifically physiological bases are generally more radical in operation, and the etiology may frequently be very complex. The possible neurological disturbances of the laryngeal action may be considered under three headings: firstly, the sensory disorders; secondly, the motor disorders; and finally, the disorders of co-ordination. Thomson and Negus, **250**, p. 589ff. The sensory disorders may be anæsthesia, hyperæsthesia or paræsthesia. They may be peripheral, or in the nerve trunks or in the central nervous system, involving the sensory fibres of the superior laryngeal nerve or bulbar lesions, as in tabes, sclerosis, hæmorrhages or tumours. These may occur in cases of anæmia, hysteria, neurasthenia, dyspepsia or alcoholism. The sensory control of respiration and phonation may be directly affected.

§ 38·2. **Larynx.** The motor disorders of the larynx are highly important, especially in the less easily diagnosed

dysfunctions of the vocal cords in singing. Tarneaud, **247**. The disorders may be hyperkinetic and spasmodic, involving clonic spasms of the glottis, or hypokinetic and paretic and paralytic, involving tonic fixation or inaction of the vocal cords and larynx muscles. They may result from paralysis agitans, syphilis of the brain, pressure in the medulla, tabes dorsalis, or more commonly diffuse arteriosclerosis and disseminated sclerosis in the first case, and in the second case lesions or pressure upon the motor fibres in the vagus or of the recurrent laryngeal nerve from intracranial growths, growths in the neck or thorax, or degeneration in the medulla. The form taken by laryngeal muscular hypertonicity involves reduced vibratory amplitude and a harsh voice quality, accompanied by contraction of the glottal opening and downpressing of the ventricular bands upon the vocal cords. The form of the muscular hypotonicity varies according to the type and extent of the paresis or paralysis. In paresis of the adductor muscles—the interarytenoid, lateral and posterior cricoarytenoid muscles—the results are incomplete closure of the glottal chink and a wedge-shaped gap between the arytenoids at the posterior end of the vocal cords. This may sometimes be seen only on high pitches or ascending scales. Paresis of the thyroarytenoid muscles is shown by increased vertical movements of the cords in vibration as well as by flecks of mucus along the surfaces of the cords. Apparently, in cases of the vocal cord inaction it is much more commonly the left cord which is paralysed, possibly because of the longer path of the left recurrent nerve, and hence the greater danger of local pressure or lesions. Tilley, **374**, p. 369. Paralysis of the superior laryngeal nerve, involving the cricothyroid muscle, results in lack of fixation of the thyroid on the cricoid. The cords assume a wavy edge and tend to flap up and down in expiration and inspiration. The lesions of a cortical nature would need to be bilateral to have a localized effect on the larynx. Lesions at the bulbar level are more likely and lesions of the motor tract in the vagus or recurrent nerve are most common. These may occur

through local pressure by growths in the neck, especially of the thyroid glands, or aneurisms of the internal carotid artery or goitre. They may also result from metallic or other poisoning, exposure to cold, or inflammatory infiltration from malignant growths of the pharynx, tuberculosis, syphilis or foreign bodies.

§ 38·3. **Co-ordination.** Disorders of co-ordination are presumably of cerebral origin. The more localized disorders take the form of choreic movements, phonic spasms, nervous laryngeal cough and laryngeal vertigo. In a progressive organic lesion of the laryngeal muscles the order of involvement is: firstly, the abductors; secondly, the tensors; and thirdly, the adductors (Semon's law). This form of laryngeal paralysis is almost always a bulbar and not a cortical lesion. In destruction of one cortical centre the opposite centre can act for both sides; the destruction of both sides is necessary for paralysis. Cases of tabes dorsalis, sclerosis and cretinism frequently exhibit trembling of the lips and spasmodic movements of the tongue. Bristowe, **218**, p. 91. In deaf-mutism, either congenital or acquired, the respiratory rhythm varies greatly from the normal, showing often a considerable halt after inspiration, and, above all, a disco-ordination of diaphragm and thoracic synchronism and sudden expulsions of large quantities of air. Mitrinovitch, **313**, p. 216. The speech of the blind tends to be faulty in the articulation of speech sounds involving careful co-ordinations. There are often somatic disturbances which accompany blindness, such as nasal, oral or pharyngeal malformations, lack of muscle tonus and defects of phonation. The voice is thus often flat and monotonous, unusually loud and full of omissions and transpositions of sounds. Eisenson, **143**, p. 163. Little is known of the cortical association areas in their function in the more complex types of co-ordinations of visual, kinæsthetic and auditory factors in voice and speech. Strasburger, **359**, p. 39.

§ 38·4. **Cerebral Lesions.** The major type of cerebral lesion involving paralytic defects of speech is described

collectively as spasticity, and the speech of these cases as spastic speech. The speech is often accompanied by facial contortions, such as puckering of the lips, squinting of the eyes and twitches of the facial muscles. West *et alia*, **185**, p. 109ff. There are also likely to be many psychological disturbances of behaviour and personality. The spasticity results from the lack of inhibition by the cerebral centres, from which the various lower levels of the central nervous system are controlled. This deficiency of cerebral control allows stimuli to affect strongly the motor neurones at the lower levels. The result is muscular hypertonicity producing in the larynx excessive tension of the vocal cords and the laryngeal muscles. The voice shows little control of pitch change save that of an uncontrollable quavering type ; the intensity is usually fixed and excessive ; the quality is husky even to the point of aphonia as a result of the hypertension. In articulatory actions the more complex patterns are simplified and many sounds are levelled under one type form. Complex groups of consonants are reduced by elision or transposition. Parkinsonian facial rigidity is shown by the defective articulation of the labial consonants. Hypertension of the palatal muscles may result in continuous nasality of the voice. The spastic cases frequently show symptoms of neuropathology—athetosis, dysphasia, amentia or psychosis. The thought-content and memory for language may be radically affected.

§ 38·5. The neuropathological symptoms which may accompany speech defects in these cases may vary greatly according to the area and extent of the brain injury. Athetoid movements, or slow, rhythmic tonic spasms of the antagonistic muscles, may appear as the major symptoms. In the voice athetosis is shown as an involuntary and haphazard change of pitch or a marked tremor in pitch and intensity. These symptoms are much more frequent in cases of emotional stress. There is often a functional inequality of analogous unilateral muscle groups exhibiting a tonic asymmetry or an impaired co-ordination of movement. This may be associated

with sensory inequality for unilateral vision, hearing, touch or kinæsthesia. Disorders of the respiratory rhythm and a higher emotional excitability are also likely. The psychopathic symptoms may be as severe as that of mental deficiency or amentia, though spasticity does not always accompany amentia and, *vice versâ*, amentia does not always accompany spasticity. Psychoneurotic disorders of personality and bodily functions may occur. The spastic may not have the social complement of inhibitions, and may be very extrovert and exhibitionistic in behaviour. It would frequently seem as if the censorship of the ego were weakened or absent and the uncontrollable impulses of the unconscious were given full opportunity for expression of anti-social behaviour. The normal sequence of sleep cycles may be upset during and after the spasms, so that the spastic may be drowsy in the day and wide awake at night. A secondary amentia, an acquired mental impairment and failure due to special disabilities, will show as a specialized stupidity in the performance of certain actions with a degree of intelligence in the performance of other actions. It is the picture of a patient suffering from a localized disorder of cerebral control.

§ 38·6. **Chorea.** Irregular, jerky muscular activity and twitches are symptomatic of chorea, of which the minor variety, known as Sydenham's chorea, is most prevalent in childhood between the ages of five to fifteen years, and more frequently in girls than in boys (5 to 2 is the average ratio). Chorea is apparently associated with rheumatism, tonsilitis, and a dietary deficiency of fat-soluble vitamin D. It is an infectious, toxic state resembling vascular, degenerative, inflammatory encephalitis. The form of chorea major, or Huntingdon's chorea, appears in later life at about thirty to forty years, is probably hereditary, and partakes of the nature of senile decay and dementia. Chorea minor has certain definite speech involvements, the principal being irregular, clonic spasms of the speech muscles, producing jerky, broken speech and spasm of the respiratory muscles. The clonic spasms are distinguishable by their irregularity

from the tonic, rhythmic movements of athetosis. The incipient stages of chorea are marked by general restlessness, inattention and clumsiness. In chorea major, the muscles of gait, face and speech may be affected and reflexes exaggerated. Facial contortions and thick, slow speech result, with a good deal of aspiration. Mental degeneration and mutism are likely to ensue, and apraxia is often present.

Psychological Disorders

§ 39·1. In the discussion of the speech disorders of the primarily psychological nature, it is possible to give only generalizations concerning the many varieties of symptoms found in these cases. In following the classification of these disorders into neuroses, psychoneuroses and psychoses, it will be seen that the major symptoms are those of the personality disorders and that the actual speech disorders are subordinate manifestations. Two common types of neurosis are the anxiety state and the neurasthenia. Apparently there is a certain degree of association between neurosis and subnormal intelligence. There is also indication of mental and physical exhaustion and underactivity. Disorders of sleep, and of the circulatory, digestive and urogenital systems are common and the especial manifestations associated with speech take the form of facial tics, tremors of the speech organs and clonic spasms of the respiratory and larynx muscles. It is a possible source of the initial trend towards stuttering, especially in adults. Stinchfield, **176**, p. 147. The mental debility may be extended to any manifestation of mental exertion : reading, writing, concentration. The state may result from a failure of a witting attempt at repression of unconscious urges. The repeated failure of this repression may become chronic.

§ 39·2. **Psychoneuroses.** Various types of speech disorders occur in the symptomatology of the psychoneuroses, especially in the hysterias, psychæsthenias, and compulsion neuroses and obsessions. They may be concerned with the form of the psychic taboo on sexual topics and trends and centred round

specific words and concepts. In hysteria the marked characteristic is the conversion of the psychic disorder into a physical one, with the accompanying symptoms of pareses, paralyses, epileptiform seizures, convulsions and aphonia. The symptoms may be considered as remnants or memory symbols of the traumatic experiences. Jennings-White, **213**, p. 65. The repressed emotion is converted into motor and sensory innervation for the muscles performing actions more or less connected with the traumatic experience. Aphonia in these cases is a defence mechanism partaking of virtual immobility and hence preparedness of the body against attack. Spasms of the face, lips and tongue may occur, and when speech returns it is often of a hoarse quality or even a stutter. In the compulsion neurosis the uncontrollable urge to perform an action may take the form of a speech disorder, especially a stutter. This may be the result of a transference, whereby the oral aperture of the mouth has taken on a repressed auto-erotic significance, and may represent in the unconscious of the patient the anus or the urethra. English and Pearson, **125**, p. 107. A less severe form of hysteria appears in stage-fright, when there is a reaction of muscular tension towards the feared object or situation. The reaction may come upon the cue of the special stimulus or anything connected with it. The results are aphonia, loss of memory, or an exaggeration of pitch, intensity and rapidity of speech.

§ 39·31. **Psychoses.** The manifestations of speech disorders in psychoses are probably in the form of secondary symptoms indicative of the mental unbalance and deterioration in these cases. The three major classifications of psychoses are firstly, paranoia, involving systematized delusions of facts and actions; secondly, schizophrenia, or dementia præcox, involving a seclusive attitude with emotional dullness and indifference; and thirdly, manic depressive insanity, involving a group of states varying from overactive aggression to stupor and a state of simulated death. In these cases the speech disorders are secondary indications of the state of

mind, and the manifestations may vary from high excitability, rapid and loud speech, to a slow, stunted, meaningless utterance of monosyllables. In the paranoid state the speech varies according to the form and dimensions of the delusions. Delusions of grandeur will cause a marked pompous, aggressive speech, while delusions of persecution will be marked by trembling voice and repeated indications of fear and revulsion. The thought content of the paranoid speech is logical though based upon distorted assumptions and strongly self-referrent. There are no obvious signs of mental deterioration until some anti-social act or speech is produced.

§ 39·32. In the schizophrenic the speech manifestations are varied, but characterized by fantastic, inconsequential thoughts and lack of sequence of ideas and modes of expression. Penrose, **132**, p. 21. There is a frequent absence of connection between successive thoughts and words and the grammatical linkage forms of conjunctions and prepositions are often omitted. The form of linguistic expression may be normal, but the sequence of concepts may be entirely incoherent, and there may be senseless repetitions and an irrelevant transfer to thoughts suggested by purely superficial characteristics of speech, such as rhymes and puns. In the simplest form there may be apathy and lack of interest in the thought-content of speech as indicated by a monotonous stereotyped articulation of meaningless words and phrases. In manic depressive insanity the form of the speech manifestations may vary according to the state of the mind. In the manic phase, under the delusion of grandeur and well-being, hallucinations of power and illusions occur with pompous, verbose, rapid speech upon a whole variety of topics connected more or less irrelevantly with the immediate circumstances. The patient is usually fairly alert to the surroundings and bursting to express himself on all possible topics. There is loss of control and inhibition of speech content and all kinds of normally repressed topics may be discussed. In the depressive phase the opposite state appears.

The speech becomes that of a mentally retarded, hopeless and stupid person. The patient may become inattentive or even mute, and may concentrate his attention upon or discuss auditory hallucinations and delusions of a painful nature which may occur frequently.

The Linguistic Disorders

§ 40·1. The classification of certain types of speech disorder as primarily linguistic is arbitrary and useful only to bring together in this discussion some of the varied manifestations of purely cerebral disorders of communication. The types of cerebral disorder to be considered here are, firstly, dysphasia, and secondly, amentia. The composite term dysphasia is used here to designate disorders of language due to disturbed mental imagery. It therefore includes agraphia, alexia, articulatory aphasia, word deafness, mixed aphasia and total aphasia. The cortical localization of the functions of mental imagery and the memory for writing, reading and hearing is not as yet very definite, and there is considerable variance of opinion concerning the relative importance of the various cortical association areas situated near the recognized motor and sensory nerve endings. Strasburger, **359**, p. 39. These association areas are represented in both hemispheres, but there is some evidence that in the right-handed person the left brain centres predominate over the right centres, especially in expressive speech. This is probably due to the occurrence of a controlling, specialized area in the third frontal convolution of the left hemisphere for right-handed persons, and known as Broca's area. Dysphasia is most commonly a vascular disturbance of one or more of these association areas or hæmorrhage of the mid-cerebral artery in apoplexy. The periods of greatest incidence are in babyhood and in old age. The distinction between feeble-mindedness (primary amentia) and dysphasia (secondary amentia) is based upon sharp differentiation between varied mental faculties. Primary amentia, which is a condition of the germ-plasm, shows general stupidity in all ways ; dysphasia

shows stupidity in specialized directions with possible intelligence in other ways.

§ 40·2. **Dysphasia.** Dysphasia in childhood is often difficult to distinguish from hearing loss, especially that for high frequencies. Ewing, **244.** The power of pitch discrimination is an average example of a good test of hearing, but under circumstances of a peculiar type the aphasic child may not even show awareness of a sound he actually hears. In this case a conditioning of the child to a sound stimulus and an accompanying blow on the body will often show the presence of some remnant of hearing. The hearing but aphasic child will be conditionable, when the deaf child will not. West *et alia,* **185,** p. 125. In the adult dysphasia shows a more marked differentiation between mental abilities and disabilities, often presenting a curious picture of disparate functional ability. In auditory aphasia the meaning of spoken words is lost ; in articulatory aphasia the power to answer in speech to written questions is lost. More generally, however, the dysphasia is of a mixed type exhibiting a variety of reactions to varied situations of speech and writing. Stinchfield, **176,** p. 162. The dysphasic is handicapped in social adjustment to a world for which he is not fully equipped, and he frequently develops a state of subjection and emotional weakness. Total aphasia involves a complete loss of speech for which there are both motor and sensory disorders.

§ 40·3. **Amentia.** The concept of amentia is that it is a state of developmental failure incorporating continuous gradations of feeble-mindedness from that of the idiot, who is unable to protect himself against common dangers, the imbecile, who is incapable of earning a living but can protect himself, to that of the moron, who is capable but needs supervision and control. It is a general mental inferiority in all forms, especially shown in language by an incapacity of symbolism. Specific types of inferior development are, firstly, the cretin, which is characterized by infantilism of development in point of bodily size ; and secondly, mongolism, a state similar to cretinism with additional afflictions of

deafness, anatomical deformations of the speech organs and hoarse phonation. Cretinism is apparently due to hypothyroidism in early life. The etiology of mongolism is still rather obscure, and various factors ranging from parental syphilis to exhausted reproductive powers and faulty sugar metabolism have been adduced. It is probably a pathological condition of the endocrine system, but it is difficult to know which especial glands are involved.

§ 40·4. **Cretinism.** The symptomatology of cretinism is that of a mental and emotional state in keeping with the physical retardation. Superficial judgment may presuppose a certain intelligence, but in later life the cretin becomes stupid and sluggish. Speech therapy is really rather wasted unless glandular diagnosis and treatment are producing some satisfactory results. Without a speeding up of maturation the speech therapist can do little of value. West, **185.** In the case of mongolism there is a similar absence of much hope for successful speech therapy. The speech is ataxic and uncertain, involving failure to articulate the front consonants, such as [s, z, f, v, *θ*, ð, l, ɹ]. Voelker, **386,** p. 266. The mongol shows signs of intelligence in certain actions, mostly associated with visual stimuli and memory. Speech therapy is of little use unless the medical diagnosis shows hope of successful treatment.

CHAPTER X

VOICE AND PERSONALITY

§ 41·1. There are numerous occasions in normal life when the association between voice and personality becomes a matter for judgment and examination. With the advent of telephonic and radio communication, or the sound record on a disc or film or steel tape, the voice of a speaker may be conveyed in a form entirely dissociated from the visible appearance of the person. The legal question of the reliability of voice identification aroused by the Hauptman trial in the United States of America has been the stimulus for a recent study. McGehee, **199**. Apparently the court procedure of accepting testimony of positive identification by voice after a time interval is subject to grave doubt. Nevertheless, many people listening to a voice on the radio broadcast make judgments of personality with a certain degree of confidence in their accuracy. Linguistic features of accent and dialect have been investigated in this way by public broadcasts of highly individual voices and speech. Pear, **163**. In considering the technique and validity of these investigations, certain important distinctions between voice and speech must be realized. Sapir, **206**. Firstly, it is evident that, unless only single speech sounds are uttered discretely, the judgments of personality are based upon the total characteristics of voice in the wider sense. The accuracy in recognizing a singing voice may become very great after a training and conditioning of the judge. The recognition of a given singing voice by such a skilled judge is based upon observation of the acoustic characteristics of the voice: viz., pitch, intensity, duration and quality, in the forms which the singer employs in rendering a given composition.

The compositional factors of melody and words may be of little or no importance in this judgment. In speech, however, the same characteristics of voice are joined with the linguistic factors of vocabulary, pronunciation, grammar, linguistic style and phraseology to constitute the normal recognizable entity.

Judgment

§ 41·2. Auditory judgments of personality are accordingly based upon the recognizability of the temporal patterns in the acoustic factors in a given voice and the given sample of speech. In any such sample of speech, for test purposes the linguistic factors should be maintained relatively invariable throughout the performances of the various speakers under test. For this reason it is desirable that experimenters on the association of voice and personality should ensure that their subjects achieve relatively identical performances in respect to the duration, intensity patterns, intonation patterns, and rhythmic patterns in both the parts and the whole of the test passage. If this is not done, the test is invalidated by the fact that the judgment is being conditioned by linguistic factors which are not necessarily connected with the personality of the speaker. An experimenter who is concerned with the dialect or accent of his subject is testing not the personality of the subject but the linguistic community to which the subject belongs. Accordingly, it may occur that a speaker's profession may be judged on the basis of a given linguistic trait, as, for example, a psychologist from South Africa with an 'English' accent, who was judged by American students to be a professor of English. Allport and Cantril, **188**, p. 45.

§ 41·3. In examining the details of such experiments as have been made to test the correlation between voice, speech and personality, the more positive results are found in the judgment of psychological factors, such as extroversion against introversion, aggression against submission, or gross physical factors, such as the voice of a short corpulent

speaker against that of a tall, asthenic speaker. Allport, **188**, p. 46. There is no doubt that certain characteristics of speech are recognizable as symptomatic of individual typical attitudes towards social behaviour. Thus the aggressive attitude is most frequently characterized by loud, emphatic speech containing assertive statements conveyed in a forceful use or misuse of linguistic forms. The total content of the individuality of a person may be considered to belong to two sets of determinants. These are, firstly, the physical factors of age, sex, habitat, anatomy, physiology; and secondly, the psychological factors of character, occupation, status in society and attitudes. Accordingly, the judgment of the association between voice and personality must be largely conditioned by the particular ' Gestalt ' in which the judge is incorporated and by his experience of and reactions towards the physical and psychological determinants of individuality. Stagner, **173**, p. 10.

§ 41·4. **Physique.** In the judgment of physical factors of personality from the cue of voice, it is quite obvious that the preconceptions and background of experience of the judge will play a large part in determining the accuracy of the judgment. In judging sex by voice, it is to be expected that judges will recognize voices of the opposite sex rather more readily than those of the same sex. This is due to the fact that in acoustic judgments it is easier to distinguish between dissimilar sounds than to associate together similar sounds. This assumption has been confirmed by such experiments as have been conducted on these lines. McGehee, **199**, p. 265. In the judgment of age from voice the degree of accuracy may be quite high, though there is a tendency to telescope the range of age around a median value of thirty-five to forty years. Pear, **163**, p. 175. This consists of underestimating the age of old voices and overestimating that of young voices. Allport, **188**, p. 42. Since the majority of the judges in these experiments must have belonged to the age range of twenty to forty-five years, this tendency to condition age judgment by comparison with voices in their

own circle of acquaintances is quite understandable. In the co-ordinated judgment of sex and age it is obvious that children will be most difficult to distinguish as to sex, since the voices of the two sexes are much more similar at that age than after puberty.

§ 41·5. **Race.** Judgments of race by voice are likely to be very variable and dependent upon the experience of the judge. Actually, it is very doubtful in this form of judgment whether the voice and speech characteristics can be separated one from another. Experiments on these lines are apt to betray an ignorance on the part of the experimenter of the linguistics of the speech community. Pear, **163**, p. 4. Thus, when we listen to an unfamiliar foreign speaker, we are listening as much to the speech as to the voice and our judgments are based upon both factors. Furthermore, the linguistic factors are by far the more important in these judgments. The more thorough the comprehension of the languages in question, the more accurate will be the judgments of race. Judgments of habitat are likely to be purely adventitious and freakish, being dependent upon specialized knowledge on the part of the judge. It is very doubtful whether factors of climate and habitat have any considerable influence on the voice ; such differences as may be noted are most probably linguistic in origin.

§ 41·6. **Constitution.** Judgments of anatomical and physiological constitution may well succeed in cases of gross distinctions. This occurs frequently in singing when the correlation between a low-pitched, intense voice and a male, heavy, large-framed constitution is quite close. Likewise, the probable correlation between a soprano voice and a female, light, small-framed constitution may also facilitate such a judgment. In attempting to go beyond these gross distinctions, one must be careful not to resort to the practice of forcing psychological attitudes into a preconceived framework of physical types. A male, small light-framed person may well cultivate a low-pitched, intense voice for the deliberate purpose of venting an aggressive impulse. Con-

versely, a female, slight-framed person may well develop the low-pitched, intense voice by reason of endocrine unbalance or even functional laryngeal disorders. It is much more likely that the normal voice may indicate the physiological concomitants of a psychological attitude than that the voice quality is a direct result of a given physical constitution in all cases. In pathological cases, however, the voice quality is usually a direct symptom.

Individuality

§ 42·1. The psychological determinants of individuality are more likely to produce specialized characteristics of voice than are the physical states. The principles of freudian depth-psychology have done a great deal to explain the motivation of certain voice qualities, which are recognizable by the hearer as symptomatic of definite attitudes. While the primary function of voice is the communication of ideas, the secondary function of oral aggression by voice may assume increased importance under special circumstances. Hence words may become weapons and the utterance of speech an oral, aggressive or sadistic attack upon external objects. Roucek, **205**, p. 383. The particular form of voice and speech adopted for the expression of the attitude depends largely upon the linguistic tenets of the speech community comprising the individual and the external objects. In a language such as English, in which intensity and pitch are not primarily linguistic phonemes but are secondary means of expression of emotion and hence attitudes, the aggressive impulse is generally shown by an intense utterance on an extended pitch range. Accessory actions may accompany the speech and take the form of leaning forward or jerking the head forward and even be carried so far as spitting. In another language, in which the phonemic structure is different, the expression of emotion is naturally different. Conversely, the attitude of masochism may be expressed in spoken English by a voice-intensity below the average and a monotonous utterance.

§ 42·21. **Character.** In following the freudian account of the formation of character on the basis of the successful or unsuccessful transitions through the three stages of libidinal preoccupation, at the oral, anal and genital levels, respectively, the association between voice and character becomes more understandable. Fixations at, for example, the anal level constitute the origin of well-defined character habits in later life, and some of these may be associated with characteristics of voice. The habits of orderliness, parsimony, stubbornness, which are common in a great many people in varying degree, are accompanied by a definite orderliness and parsimony of voice. The pitch range and intensity of the voice are restricted and the voice quality is described as ' cold ' and ' dispassionate.' The utterance of these persons is characterized by restraint and thriftiness of words. Naturally, this comparison cannot always be applied as a principle of analysis from the voice back to the underlying attitude, since the same end-effect may be reached by way of different paths. The wider the experience of these attitudes and their effect on voices the more easily the underlying attitude will be recognized in a given voice quality. The psychoanalyst consciously or unconsciously relies greatly on this faculty of his judgment of the patient's reactions. A recklessness and disorder of habit may be expressed by a similar recklessness and confusion of utterance in the form of rapid, badly formed speech with a lavish use of intonation, stress and loudness. The adoption of either of these contrasted attitudes may be occasioned by a psychic identification with an individual who normally possesses such a type of voice. Thus a child, having parents of very contrasting types, the father noisy, loud and emotional in voice, and the mother restrained, quiet and of almost inaudible voice, may show an identification with the mother by adopting the quiet inaudible voice. Thorner, **210,** p. 199.

§ 42·22. **Attitudes.** The degree to which a particular attitude is expressed in voice will depend upon the quantity of the total libidinal urge which is directed into the function

of voice. As language has developed from the simplified form of communication to the more complex structure of the present organization, more and more of the accompanying physical signs of action such as gesture, gait, etc., have been subordinated and incorporated into the purely vocal function. Even in the more predominantly vocal modes of expression, remnants of accompanying physical symptoms, such as a facial contortion or a glint in the eye, may remain. It is probable that the recognizability in voice of a given attitude depends upon the completeness or otherwise of the direction of the total libidinal energy into voice. In the psychoanalytic concept the individual may be possessed of a finite quantity of this energy at any given moment, and this may be directed in part or whole only one way at any given time. Hence an ambivalence of attitude may result in a corresponding ambivalence of voice quality tending to a confused judgment of personality. Moreover, since words can be generalizations applicable equally to a group as to a single object, it is possible that a word may be involved in an act of transference of affective reaction so that the word can be an emotional stimulus under diversified connotations.

§ 42·31. **Behaviour.** In general, behaviour can be considered to comprise two types of responses to situations: firstly, the adaptive or biologically and socially adequate responses; and secondly, the non-adaptive responses, that is, those directed not to serve an immediate biological or social need. Stagner, **173**, p. 5ff. The personality of the individual is made of a system of habits consisting of non-adaptive ways of adjusting to conflict situations. Personality can be analysed into traits, which in turn can be considered as integrations of specific indicators, each of which is a specific act in a specific situation. The observed facts of behaviour consist of, firstly, the overt reactions; and secondly, the implicit reactions both conscious and unconscious. Both classes of behaviour can exist together in a form of dualism. In the composition of personality all vocal reactions are symbolic reactions. They are conditioned responses referring

back to an original situation and action. Stagner, **173**, p. 53. The more obvious the reference, the more explicit the motor content of the vocal behaviour. Thus the low pitch and reduced intensity of the voice in parting from a friend may stand for the more direct lamentations that might be indulged in by another.

§ 42·32. Behaviour must be considered to possess only a limited scope for variation. The observed infinity of variation in vocal behaviour must be attributed to the infinity of external objects. The major principles governing the affective reactions to external objects are, firstly, the pleasure-pain principle ; and secondly, the reality-non-reality principle. The second arises out of the first as a modification of the blind pursuit of the first principle. Part of the organized repressive or inhibitory conditionings thus created may be called the conscience. It is apparently the part organized in response to verbal stimuli, hence the frequent simile of the voice of conscience. Stagner, **173**, p. 91. In the same manner, the rationalization of action consists of a verbal justification of behaviour. Stagner, *op. cit.*, p. 104. The flight from reality observed in cases of schizophrenia may be justified to himself by the patient by a rationalization applicable only to the phantasy world he has created for himself. Accordingly, the vocal symptoms peculiar to this state may be rational enough in reference to this phantasy world.

§ 42·4. **Occupation.** The association between voice and occupation is likely to be significant, especially in those occupations in which the bulk of the non-adaptive reactions of behaviour are vocal. Hence the teaching, ecclesiastical, legal and military professions are each likely to foster an individual mode of vocal reaction to external situations. These modes are conditioned by the habits of the speech community to which the individual belongs. The mode must therefore be judged in relation to that speech community. The speech characteristics by which we judge a given mode may be purely linguistic, such as the cultured and extended

vocabulary of the academic profession, the specialized phraseology and archaism of the legal profession or the aggressive, commanding vocabulary of the soldier. In this sense, we may say that now the spoken language has created the personality while in the beginning the personality of man has created that faculty of voice which more than anything else distinguishes him in personality from the rest of the natural world.

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